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PROFESSIONAL PAPER 130

THE LARAMIE FLORA OF THE DENVER BASIN

WITH A REVIEW OF THE LARAMIE PROBLEM

BY

F. H. KNOWLTON

WASHINGTON
GOVERNMENT PRINTING OFFICE
1922

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THE LARAMIE FLORA OF THE DENVER BASIN,

WITH A REVIEW OF THE LARAMIE PROBLEM.

By F. H. KNOWLTON.

INTRODUCTION.

In the investigation of the Laramie flora which I began about 1889 it was my original intention to study the flora of the Laramie formation of the entire Rocky Mountain region, over which the formation was then understood and generally accepted as being widely distributed. As a preliminary to this study the older collections, which had served as the basis for the work of Lesquereux, Newberry, and others, were critically reviewed. To this basis was to be added the new material that was becoming available in ever-increasing volume. It very soon became evident, however, that opinion concerning the Laramie formation was undergoing a transition, during which, as will be shown in the historical review which follows, area after area was found to have been incorrectly or unwisely assigned to the Laramie. The work was consequently delayed pending the settlement of these disputed points, and subsequent events have abundantly proved the wisdom of postponement, for otherwise the result would have been a composite picture and open to the same objections as those that fall upon Ward's "Flora of the Laramie group." The revision of the older material, together with the descriptions of such new material as came to hand from time to time, has consequently lain in manuscript for many years, though it has been available and has furnished the basis for numerous tentative considerations of this flora.

In view of the uncertainties as to the ultimate classification of certain of the supposed Laramie areas, it was finally decided to restrict this account to an area about which there is little or no disagreement. The Denver Basin in Colorado offers such an area. The geologic relations of the Laramie as understood in 1895 were set forth by Emmons, Cross, and Eldridge in their monograph on the geology of the Denver Basin.[1]

After the segregation of the Arapahoe and Denver formations from the Laramie, there remained the Laramie unit as now accepted, which is believed to fulfill in all essential particulars the requirements of the original definition by King. When the Denver Basin monograph was published, it was supposed that the coal-bearing Laramie rocks were present throughout the Front Range. Subsequent study has shown, however, that the Laramie is not now known to extend beyond Colorado Springs on the south.

This paper deals with the plants known from the Laramie of the Denver Basin, which is here considered as slightly larger than the limits set in the monograph above mentioned, extending from the vicinity of Greeley to the divide near Palmer Lake on the south. The southernmost exposure of Laramie rocks in the Castle Rock quadrangle is in practical continuity with the Laramie in the Denver Basin and is separated by a covered interval of only about 18 miles from the nearest exposure of Laramie in the Colorado Springs quadrangle. To the east the Laramie extends for varying distances out on the plains, where, however, it is more or less deeply covered by the Arapahoe or Denver formations or the Dawson arkose.

The material on which this paper is based was derived from many sources. Most of the original material on which Lesquereux based his studies is preserved in the United States National Museum and has been freely consulted. It was collected in part by F. V. Hayden and in part by Lesquereux or by persons in correspondence with him. The very earliest collection made by Hayden, at Marshall in 1867, is apparently lost. The types of the few species described by J. S. Newberry are also preserved in the United States National Museum. About 1884 an important collection was made for Newberry by N. L. Britton, now of the New York Botanical Garden. The larger part of this collection came from mines near Erie, Colo., from which no additional material has been procured. Other parts of this collection were made at Marshall and on Coal Creek. All this material has been placed at my disposal by Dr. Arthur Hollick. Considerable collections were made by Lester F. Ward in 1883, but heretofore they have only partly been described. During the prosecution of the work which resulted in the publication of the Denver Basin monograph, Emmons, Cross, and Eldridge obtained a number of small collections, and under the instructions of Emmons larger and important collections were made by Arthur Lakes and G. L. Cannon. These collections, made in 1889 and 1890, have not before been described. A small collection from Crow Creek, near Greeley, was made in 1896 by T. W. Stanton and me. The largest collections obtained in recent years were made by A. C. Peale and me in 1908. The material in the museum of the University of Colorado, at Boulder, has been placed at my disposal by the custodian, Judge Junius Henderson. Smaller collections or individual specimens have been communicated by T. D. A. Cockerell, of Boulder; R. D. George, State geologist of Colorado; G. L. Cannon, of Denver; G. B. Richardson and M. I. Goldman, of the United States Geological Survey; and G. I. Finlay, formerly of Colorado Springs. Invaluable data regarding the supposed upper part of the Laramie were obtained by W. T. Lee, of the United States Geological Survey, in 1915. To these men and all others who have contributed to this study the appreciation of the writer is hereby expressed.

---

[1] U. S. Geol. Survey Mon. 27, 1896.

Notwithstanding the fact that these very considerable collections have been brought together, the flora is neither large nor very impressive. In the first place, although plants are widely distributed in the Laramie, they are rarely found in any great abundance. The matrix in which they occur is usually a soft, friable sandstone which is not fitted to retain the plant impressions with fidelity, and, moreover, it is difficult to find perfect specimens. In attempting to present as complete a picture as possible of the plant life of the time, it has frequently been necessary to characterize forms on rather slender data. It is hoped, however, that all are figured and described adequately enough to be recognizable in the future.

A word should be said concerning the two styles of plates in this report. Plates XX–XXVIII were made a number of years ago, when it was the custom to make pen drawings of the specimens. These were drawn on an enlarged scale, requiring a one-third reduction to bring them to natural size. The figures on Plates I–XIX were photographed natural size and merely have had the outlines and nervation strengthened. The impossibility of having the two styles of drawings mixed on the same plate accounts for the scattering of the figures.

PART I. HISTORICAL REVIEW OF THE LARAMIE PROBLEM.

EARLY OPINIONS CONCERNING THE COAL-BEARING ROCKS OF THE ROCKY MOUNTAIN REGION.

As this report is the first of what is proposed to be a short series of papers dealing with the stratigraphy and paleobotany of certain late Cretaceous and early Tertiary formations in the Rocky Mountain region it is thought desirable to present rather completely a historical review of opinion which led to the establishment of the term Laramie and to its subsequent application. This review includes not only the Laramie formation in its typical area in the Denver Basin of Colorado, but also various beds at one time considered to be of Laramie age. For more than 60 years what finally came to be known as the "Laramie problem" has been more or less of a storm center in American geology. Its discussion has given rise to an extensive body of literature, and it is only within the last decade that a solution has been arrived at which, at least to me, appears to be logical and, it is hoped, permanent.

The history of the Laramie formation, as already intimated, is long and complicated, and the literature is widely scattered through a series of papers and reports in a manner that is very confusing to one who attempts to gain a comprehensive knowledge of it. A number of articles have been published dealing more or less completely with the historical development of the Laramie problem. One of the most complete for its time was that by Lester F. Ward,[2] published in 1886. Five years later C. A. White [3] again reviewed the subject as it finally appeared to one who had taken a large part in shaping it, and in 1906 George P. Merrill [4] devoted a special chapter to the Laramie question, which he ranked with the well-known "Taconic question." The "Index to the stratigraphy of North America," by Bailey Willis,[5] also contains valuable data on the Laramie formation, especially as regards certain of the later phases of opinion regarding it.

Although the term Laramie first appeared in print in 1875, it is essential, to understand the conditions which led up to the use of the term and made it necessary, to go back at least as far as 1854, the date which marks the beginning of F. V. Hayden's explorations in the Missouri River region. As Ward [6] says:

> From the circumstance that at nearly all places where it has been recognized it consists to a greater or less extent of deposits of lignite or coal, this condition was for a time inseparably associated with it to such an extent that there was a disposition to regard all the lignitic deposits of the West as belonging to the same geological formation.

Prior to the work of Hayden the presence of coal in the upper Missouri River region had been noted by Lewis and Clark in 1804–1806, by Nicollet in 1839, by Audubon and Harris in 1843, and by John Evans in 1849 and 1853, but very little was recorded by these observers concerning the geology. In 1853 F. B. Meek and F. V. Hayden were employed by James Hall, then and for many years thereafter State geologist of New York, to visit the badlands of White River for the purpose of making collections of Cretaceous and Tertiary fossils in that region. They brought back extensive collections of vertebrates and invertebrates, the latter especially from the vicinity of Sage Creek and several localities on Missouri River, mainly below Fort Pierre. Subsequently Hayden spent two years in exploration and in collecting fossils in the same general region, and in 1856 he again visited this country in connection with an expedition under the direction of Lieut. G. K. Warren.

The data acquired on these expeditions resulted in the publication of a series of valuable papers in the paleontology and geology of the Missouri River region, or Nebraska Territory, as it was then called. The first of these papers was written by Hall and Meek,[7] and although it was concerned mainly with the description of new species of invertebrates it contains (p. 405) a geologic section under the heading "Section of the members of the Cretaceous formation as observed on the Missouri River and thence westward to the Mauvaises Terres." The stratigraphic units of this section, which practically correspond to those accepted at the present day, were numbered in ascending order from 1 to 5, but they were not then named. Above the Cretaceous portion of the section was recorded the Eocene Tertiary, which was given a maximum thickness of 250 feet.

---

[2] Ward, L. F., Synopsis of the flora of the Laramie group: U. S. Geol. Survey Sixth Ann. Rept., pp. 399–557, 1886.

[3] White, C. A., Correlation papers—Cretaceous: U. S. Geol. Survey Bull. 82, 1891.

[4] Merrill, G. P., Contributions to the history of American geology: U. S. Nat. Mus. Rept. for 1904, pp. 647–658, 1906.

[5] U. S. Geol. Survey Prof. Paper 71, 1912.

[6] Ward, L. F., Synopsis of the flora of the Laramie group: U. S. Geol. Survey Sixth Ann. Rept., p. 406, 1886.

[7] Hall, James, and Meek, F. B., Description of new species of fossils from the Cretaceous formation of Nebraska, etc.: Am. Acad. Arts and Sci. Mem., vol. 5, pt. 2, pp. 379–411, 1855.

In 1856 the elaboration of the invertebrates was continued by Meek and Hayden,[8] who quoted the geologic section from Hall and Meek without change, except that the Tertiary was given a thickness of 400 to 600 feet and was said to be composed of "beds of clay, sandstone, lignite, etc., containing remains of vertebrates and in places vast numbers of plants, with land, fresh-water, and sometimes marine or estuary Mollusca." As regards the Cretaceous portion of the section they stated:

> It is worthy of note that some of the species contained in the collection from the most recent Cretaceous beds of the upper Missouri country appear referable to genera which, according to high European authority, date no further back than the true chalk, while many of them are closely analogous to Tertiary forms—so close, indeed, that had they not been found associated in the same bed with *Ammonites*, *Scaphites*, and other genera everywhere regarded as having become extinct at the close of the Cretaceous epoch, one would have considered them Tertiary species.

On subsequent pages in the same journal Leidy[9] began the publication of the results of his study of the vertebrate remains from the Judith River badlands. He did not discuss the age of the beds, but in the description of the final species, which was named in honor of the collector, he said: "This species is named in honor of Dr. Hayden * * * and which remains, I suspect, indicate the existence of a formation like that of the Wealden of Europe."[10]

In their second paper[11] Meek and Hayden took up the invertebrates that were believed to be of Tertiary age and incidentally briefly described the lithology and areal extent of the great lignite-bearing formation (=Fort Union) of the region as then known to them. They showed that it occupies a vast area, "chiefly between the forty-sixth and forty-ninth parallels of north latitude and the one hundredth and one hundred and eighth degrees of longitude." As their adumbrations, even in this first venture, regarding the age of this lignite-bearing formation are so nearly in accord with the modern interpretation, it may be of interest to quote their statement (p. 113) in full:

> Although there can be no doubt that these deposits hold a rather low position in the Tertiary system, we have as yet been able to arrive at no very definite conclusion as to their exact synchronism with any particular minor subdivision of the Tertiary, not having been able to identify any of the Mollusca found in them with those of any well-marked geological horizon in other countries. Their general resemblance to the fossils of the Woolrich and Reading series of English geologists, as well as to those of the great Lignite formations of the southeast of France, would seem to point to the lower Eocene as their position.

In the following year, however, Hayden appears to have modified his opinion regarding the age of the lignite-bearing formations, for in a short paper[12] accompanying a colored geologic map of the country bordering Missouri River, he said, in discussing the "Great Lignite deposit)":

> The collections of fossils now obtained show most conclusively that it possesses the mixed character of a fresh-water and estuary deposit and that it can not be older than the Miocene period. It is composed mostly of clays, sands, sandstones, and lignites and has yielded numerous animal as well as vegetable fossils of great perfection and beauty. It is chiefly remarkable, however, for the evidence that it reveals to us of the variety and luxuriance of the flora of that period.

In a paper immediately following that one Meek and Hayden[13] continued the description of the invertebrates of the upper Missouri River region, but before beginning the technical part of the paper they again went over the geology of the region, reaffirming their conclusion that the lignite-bearing beds are of Miocene age.

---

[8] Meek, F. B., and Hayden, F. V., Description of new species of gastropods from the Cretaceous formation of Nebraska Territory: Acad. Nat. Sci. Philadelphia Proc., vol. 8, p. 63, 1856.

[9] Leidy, Joseph, Notice of extinct reptiles and fishes, discovered by Dr. F. V. Hayden in the badlands of the Judith River, Nebraska Territory: Acad. Nat. Sci. Philadelphia Proc., vol. 8, p. 72, 1856.

[10] This is the beginning of the so-called Judith River problem, which is considered on pp. 77-78 of the present paper.

[11] Meek, F. B., and Hayden, F. V., Descriptions of new species of Acephala and Gastropoda from the Tertiary formations of Nebraska Territory, with some general remarks on the geology of the country about the source of the Missouri River: Acad. Nat. Sci. Philadelphia Proc., vol. 8, p. 111, 1856.

[12] Hayden, F. V., Notes explanatory of a map and section illustrating the geologic structure of the country bordering on the Missouri River, from the mouth of Platte River to Fort Benton: Acad. Nat. Sci. Philadelphia Proc., vol. 9, p. 109, 1857.

[13] Meek, F. B., and Hayden, F. V., Description of new species and genera of fossils collected by Dr. F. V. Hayden in Nebraska Territory, etc.: Acad. Nat. Sci. Philadelphia Proc., vol. 9, p. 117, 1857.

The next paper of importance dealing with the geology of this region was another by Meek and Hayden [14] published in 1861. In a "general section of the Cretaceous rocks of Nebraska" (p. 419) the stratigraphic units previously known only by number first received the names by which they are now so widely recognized. These are as follows:

No. 5=Fox Hills.
No. 4=Fort Pierre.
No. 3=Niobrara.
No. 2=Fort Benton.
No. 1=Dakota.

Meek and Hayden also presented in this paper (p. 433) the first complete section of Tertiary rocks of the upper Missouri River region, given in the following sequence:

Loup River beds.
White River group.
Wind River deposits.
Fort Union or Great Lignite group.

As we are concerned in the present connection only with the lower of these divisions, the others may be passed over. Their description of the Fort Union is as follows:

> Beds of clay and sand, with ferruginous concretions and numerous beds, seams, and local deposits of lignite; great numbers of dicotyledonous leaves, stems, etc., of the genera *Platanus*, *Acer*, *Ulmus*, *Populus*, etc., with very large leaves of fan palms; also *Helix*, *Melania*, *Vivipara*, *Corbicula*, *Unio*, *Ostrea*, *Pholadomomya*, and scales of *Lepidotus*, with bones of *Trionyx*, *Emys*, *Compsemys*, *Crocodilus*, etc., occupy the whole country around Fort Union, extending north into the British possessions to unknown distances, also southward to Fort Clark. Seen underneath the White River group on North Platte River. Also on west side of Wind River Mountains.

Their conclusion as to the age of the Fort Union was not very definite, owing largely to the difficulty of interpreting the somewhat conflicting plant and invertebrate evidence, but the facts that it had been observed beneath the White River deposits (regarded by them as of Miocene age but now assigned to the Oligocene) and that it contains certain vertebrate remains not known in Europe above the Eocene "strengthen the impression that this Fort Union lignite group probably represents the Eocene of Europe."

For a number of years succeeding the publication of the last-mentioned paper, or during the years covered by the Civil War, there was little scientific activity in the vast and then almost unknown Western Territories, but in the spring of 1867 Hayden secured an appropriation from Congress for the geologic investigation of Nebraska. His report on this area [15] was submitted from the field on July 1, 1867. In this he quoted without change the general sections of the Cretaceous and Tertiary rocks of Nebraska, from the paper of 1861, above mentioned. The area supposed to be covered by the "Fort Union or Great Lignite group" was greatly extended, occupying not only all the country along the Missouri from Heart River to the Musselshell, most of the valley of the Yellowstone, and northward into the British possessions, but southward as far as the North Platte and "coming to the surface again at Pikes Peak, Colorado, and extending to Raton Pass, in New Mexico." The coal near Denver and Golden, in the Denver Basin, as well as what is now known as the Canon City field and thence southward to the Raton Pass district, was considered to be of Tertiary age, and this view was affirmed the following year.[16] In Hayden's third annual report,[17] which embraced Colorado and New Mexico, the area over which the coal-bearing rocks are distributed was greatly extended. "I regard all the coal beds of the West as lower Tertiary" (p. 189) is his final word at this time.

At this point a brief review may be given of the reasons which up to this time had led Hayden and others to regard the "Great Lignite deposits" of the West as of Tertiary age. These beds had been first studied in the upper Missouri River region, where their position above the marine Cretaceous section was plainly marked. Although they were not known to be separated from the marine Cretaceous by a discordance of any kind, they were obviously above it. The paleontologic evidence, at least so far as concerned the vertebrates and invertebrates, had been found somewhat conflicting, though it favored the Tertiary side. It was the fossil plants, of which great numbers were found, that proved of most value in influencing opinion. The material, especially that obtained by Hayden while on the Raynolds expedition of 1859–60, was studied by the well-known paleobotanist J. S. Newberry. Although Newberry's report was evidently prepared and submitted as early as 1867, it was not published until 1869, when it appeared as an appendix to Hayden's account of the geology.[18] Newberry argued strongly for the Tertiary (Miocene) age of the "Fort Union or Great Lignite series." The preliminary paper in which the Fort Union plants were first described by Newberry was published in 1868,[19] though the final publication in which they were fully described and adequately illustrated was not published until 1898.[20]

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[14] Meek, F. B., and Hayden, F. V., Description of new Lower Silurian, Jurassic, Cretaceous, and Tertiary fossils, collected in Nebraska, * * * with some remarks on the rocks from which they were obtained: Acad. Nat. Sci. Philadelphia Proc., vol. 13, p. 415, 1861.

[15] Hayden, F. V., U. S. Geol. Survey Terr. First Ann. Rept., pp. 1-64, 1867; reprint, 1873.

[16] Hayden, F. V., Notes on the lignite deposits of the West: Am. Jour. Sci., 2d ser., vol. 45, p. 198, 1868; U. S. Geol. Survey Terr. Second Ann. Rept., 1868; reprint, 1873.

[17] U. S. Geol. Survey Terr. Third Ann. Rept., 1869; reprint, 1873.

The fossil plants obtained by Hayden in Colorado and Wyoming in 1867 and 1868 were studied by Leo Lesquereux, and his preliminary report on them was printed in the form of a letter to Hayden.[21] They included plants from the Laramie Plains, Wyoming, the Denver Basin of Colorado, and the Raton Mountains of southern Colorado and northern New Mexico. Lesquereux regarded the plants from all these localities as of Miocene age, a conclusion which of course confirmed Hayden in his opinion held at that date (1869) that all the coal of the West was of Tertiary age.

Up to this time there had apparently been practical unanimity as to the Tertiary age of the lignite series, "the only varying evidence being found in what Dr. Leidy considered the Wealden type of the Judith River vertebrates." The first dissenting voice to this general current belief appears to have been raised by John L. Le Conte, who had accompanied an expedition for the survey of an extension of the Union Pacific Railroad from Smoky Hill River, Kans., to the Rio Grande. The first announcement is an extract from a letter dated Fort Craig, N. Mex., October 3, 1867, published in the American Journal of Science for January, 1868.[22] In this letter he stated that he had been enabled to make an examination and determine the age of a bed of anthracite near Old Placer Mountain, 25 miles southwest of Santa Fe, N. Mex.[23] The data upon which the Cretaceous age was predicated were not given at this time but were set forth in his full report [24] published later in 1868. At a number of localities, but notably in the canyon of Purgatoire River and near Trinidad, he found undoubted Cretaceous invertebrates associated with the coal, and in the higher beds he collected plants which Lesquereux pronounced of Tertiary age. Although Le Conte's paper bears date of February, 1868, it evidently was not published on that date, for in the paper he speaks of having seen Hayden's article on "Lignite deposits of the West" in the March number of the American Journal of Science for that year. In fact, he devotes several pages (pp. 65–68) to disproving Hayden's contention that all the coal of the West was of Tertiary age. In addition to studying the rocks of the Raton-Trinidad area, Le Conte made a journey from Trinidad to Denver, noting the coal near Colorado City and in the Denver Basin at Marshall, Golden, and other places. All this coal he considered to be of Cretaceous age, in spite of the evidence for Tertiary age adduced by Hayden and Lesquereux.

Without unduly anticipating it may be pointed out that subsequent study in the Raton-Trinidad area has shown that both Le Conte and Lesquereux were right—that is, the beds which yielded the *Inoceramus* are now known to be separated by marked unconformity from those above which supplied most of the plants studied by Lesquereux. (See pp. 18–19.)

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[18] Hayden, F. V., Geological report of the exploration of the Yellowstone and Missouri rivers, under the direction of Capt. W. F. Raynolds, in 1859–60, 1869. Newberry's "Report on the Cretaceous and Tertiary plants" occupies pp. 145–174.

[19] Newberry, J. S., Notes on the later extinct floras of North America, with descriptions of some new species of fossil plants from the Cretaceous and Tertiary strata: New York Lyceum Nat. Hist. Annals. vol. 9, pp. 1–76, 1868.

[20] Newberry, J. S., The later extinct floras of North America (a posthumous work, edited by Arthur Hollick): U. S. Geol. Survey Mon. 35, 1898.

[21] Am. Jour. Sci., 2d ser., vol. 45, pp. 205–208, 1868; reprinted in U. S, Geol. Survey Terr. Third Ann. Rept., pp. 195–197, 1873.

[22] Cretaceous coal in New Mexico: Am. Jour. Sci., 2d ser., vol. 45, p. 136, 1868.

[23] Two years later F. V. Hayden visited this region and reported that the coal beds were above Cretaceous rocks containing *Ostrea congesta*, *O. larva*, *Inoceramus*, etc. The anthracite he explained as being due to the presence of an enormous dike. (See Preliminary field report of the United States geological survey of Colorado and New Mexico [U. S. Geol. Survey. Terr. Third Ann. Rept.], pp. 66–68, 1869.)

[24] Le Conte, J. L., Notes on the geology of the survey for the extension of the Union Pacific Railway from the Smoky Hill River, Kans., to the Rio Grande, pp. 1–117, 1868.

In 1869 Cope [25] published an elaborate paper on American fossil vertebrates in which he laid the foundation at least for a possible reference of certain of the localities of the Missouri River region to the Cretaceous. In discussing *Ischyrosaurus antiquus* Leidy (p. 40), which came from Moreau River in what is now South Dakota, he said that the horizon may be "perhaps of Cretaceous age," and under *Hadrosaurus ? occidentalis* Leidy (p. 98) he recorded the horizon as " ? Cretaceous beds of Nebraska, between Moreau and Grand rivers." In the same paper he refers the badlands of the Judith River to the upper Jurassic.

About this time the United States Geological Exploration of the Fortieth Parallel, under the direction of Clarence King, had reached that stage of its work which permitted the publication of the first to appear of its final reports.[26] To this volume King contributed a number of chapters, among them one on the geology of the Green River Basin of Wyoming, in which he held that the coal-bearing strata are of Cretaceous age and are unconformably overlain by fresh-water deposits of Tertiary age. On this point he says (p. 453):

> Near the summit of the 9,000 feet a looser texture begins, and this change is rendered very noticeable by the introduction of beds of coal, which for an unknown distance upward, probably several thousand feet, reappear through a zone of constantly changing sand and mud rocks. The fossil life, which clearly indicates a Cretaceous age for the deepest members up to and including the first two or three important coal beds, from that point gradually changes with a corresponding alternation of sediments, indicating a transition to a fresh-water period. The coal continued to be deposited some time after the marine fauna had been succeeded by fresh-water types. The species of fossils are in no case identical with the California Cretaceous beds, which occupy a similar geological position on the west of the Sierra Nevadas. Their affinities decidedly approach those of the Atlantic slopes, while the fresh-water species, which are found in connection with the uppermost coal beds, seem to belong to the early Tertiary period.

Regarding the unconformable relations of the beds above mentioned to the overlying Tertiary, he said (p. 455):

> Whatever may be the relation of these beds in other places, it is absolutely certain that within the region lying between the Green River and the Wasatch and bounded on the south by the Uintah Range there is no single instance of conformity between the coal beds and the horizontal fresh-water strata above them.

This same chapter contains a report by F. B. Meek on the fossil invertebrates of the region, in which he made the following guarded statement:

> With the exception of the genus *Inoceramus*, which is certainly represented by two or three species, and perhaps *Anchura*, all of these fossils, so far as their characters can be made out, appear to be just such forms as might be referred with about as much propriety to the Tertiary as to the Cretaceous. In fact, it is probable, from the general absence of characteristic Cretaceous types among them (with the exceptions mentioned) that, if submitted to almost any paleontologist not aware of the fact that the specimens of *Inoceramus* and *Anchura?* occurred in the same beds, the whole would be unhesitatingly referred to the Tertiary. * * * From all the facts now known, I can therefore scarcely doubt that you are right in referring these beds to the Cretaceous.

In this report Meek also discussed the age of the so-called "Bear River Estuary beds," a series of fresh-water beds contiguous to Bear River in western Wyoming and eastern Utah. A complete historical review of the Bear River controversy, together with an enumeration of its invertebrate fauna, was given by C. A. White in 1895.[27] A brief exposition of this matter will be found on page 78 of this report.

The Fourth Annual Report of the Geological Survey of the Territories, for 1870 (published in 1871), was devoted to Wyoming and portions of contiguous territories. In a brief review of the geology of the Missouri River region, which forms Chapter VII of this report (pp. 85-98), Hayden again insisted upon the Tertiary age of the "Fort Union or Great Lignitic," and in support of this contention quoted from Newberry's report on the fossil plants as published in the Raynolds report already mentioned. (See p. 6.) That Hayden had come to realize the possibility that the coals of the West might not all be of Tertiary age is shown by the following remark (p. 94):

> The area which it [Fort Union] occupies is not yet known, but every year it is extended north, south, and west. It is also characterized by numerous beds of coal, or lignite as it was formerly called, and, so far as the upper Missouri is concerned, most of the coal is true lignite. It is quite probable that the coal-making period began in the later portion of the Cretaceous era and extended up into the Tertiary. The observations of

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[25] Cope, E. D., Synopsis of the extinct Batrachia, Reptilia, and Aves of North America: Am. Philos. Soc. Trans., vol. 14, pp. 1-252, 1869-70.

[26] U. S. Geol. Expl. 40th Par. Rept., vol. 3, Mining industry, Washington, 1870.

[27] White, C. A., The Bear River formation and its characteristic fauna: U. S. Geol. Survey Bull. 128, 1895.

geologists in New Mexico and Utah point to the conclusion that large deposits of excellent coal occur in the upper Cretaceous.

In the same report (p. 165) in discussing conditions on the Laramie Plains, he said:

> That there is a connection between all the coal beds of the West I firmly believe, and I am convinced that in due time that relation will be worked out and the links in the chain of evidence joined together. That some of the older beds may be of upper Cretaceous age I am prepared to believe, yet until much clearer light is thrown upon their origin than any we have yet secured I shall regard them as belonging to my transition series or beds of passage between the true Cretaceous and the Tertiary.

Lesquereux also contributed a short paper to this same report in which (pp. 381–385) he gave a list of all the supposed Tertiary plants of the region known at that date. This list includes 30 species from the "Eo-lignitic" (now Wilcox formation) of Mississippi, 8 species from the Raton Pass region (now Raton formation) of New Mexico and Colorado, 9 species from Marshall, Colo. (now Laramie formation), 2 species from Golden, Colo. (now Denver formation), and 6 species from Rock Creek, Laramie Plains, Wyo. (now "Upper Laramie").[28]

In the Fifth Annual Report of the U. S. Geological Survey of the Territories, for 1871, which was published in 1872, Lesquereux has a long report on new plants from localities in Wyoming and Montana, all of which he considered to be of Tertiary age. He also attempted an important generalization in dividing the several localities among the stages of the Tertiary. This may be summarized as follows:

To the Eocene he referred the localities of Mississippi ("Eo-lignitic"); of Raton Pass, Purgatoire Canyon, and Marshall mine, near Denver, Col.; of Washakie Station, Evanston both above and below the coal, and Snake River just below [south of] the Yellowstone Park, all in Wyoming; and 6 miles above Spring Canyon, Mont. To the lower Miocene he referred the Fort Union and Yellowstone, Mont.; Rock Creek, Medicine Bow, Junction Station, and Carbon Station, Wyo.; to the middle Miocene Henrys Fork, Muddy Creek, and Barrell's Springs, Wyo., and Elko Station, Nev. The following localities were not at this time definitely placed stratigraphically: Green River, Point of Rocks, Sage Creek, and mouth of Spring Canyon.

In the following year (1872) Lesquereux himself spent several months in the study of this general field, undertaken at the direction of Hayden, as he somewhat naïvely remarks, with the "view of positively ascertaining the age of the lignite formations, either from data obtainable in collecting and examining fossil vegetable remains, or from any geological observations which I should be able to make."

During this investigation Lesquereux visited and collected from the coal fields of Marshall and Golden in the Denver Basin, Colorado Springs, Canon City, Trinidad, and Raton, and also along the line of the Union Pacific Railroad from Cheyenne to Evanston, Wyo. His results [29] were considered as confirmatory of his previous conclusions, namely, that the beds at these localities are of Tertiary age and constitute what he called the American Eocene

The same year Meek and Bannister, who were also conducting investigations along the line of the Union Pacific Railroad, made a discovery at Black Buttes which, in the opinion of many, had a very definite bearing on the age of the coal of the region. This was the finding of the remains of a huge dinosaur which was named by Cope [30] *Agathaumas sylvestris*. In his paper Cope said:

> From the above description it is evident that the animal of Black Buttes is a dinosaurian reptile. * * * It is thus conclusively proven that the coal strata of the Bitter Creek basin of Wyoming Territory, which embraces the greater area yet discovered, were deposited during the Cretaceous period, and not during the Tertiary, though not long preceding the latter.

In a short paper published later in the same year Cope,[31] in commenting on the discovery of *Agathaumas*, said: "This discovery places this group [the so-called Bitter Creek series] without doubt within the limits of the Cretaceous period, and to that age we must now refer the great coal area of Wyoming."

In commenting on the age of the "Bitter Creek series," as the beds at Black Buttes and vicinity were then designated, Meek [32] expressed himself with extreme caution, saying:

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[28] With the exception of that at the Marshall locality, all the collections above enumerated as Tertiary by Lesquereux are accepted as such at the present day, though for some of them it has required 40 years to establish the truth of Lesquereux's assignment.

[29] Lesquereux, Leo, Lignitic formations and fossil flora: U. S. Geol. Survey Terr. Sixth Ann. Rept., for 1872, pp. 317–427, 1873.

[30] Cope, E. D., On the existence of Dinosauria in the transition beds of Wyoming: Am. Philos. Soc. Proc., vol. 12, p. 481, 1872.

[31] Cope, E. D., The geological age of the coal of Wyoming: Am. Naturalist, vol. 6, p. 669, 1872.

[32] Meek, F. B., U. S. Geol. Survey Terr. Sixth Ann. Rept., for 1872, pp. 458, 461, 1873.

> The reptilian remains found at Black Butte, near the top of the series, have, as elsewhere stated, been investigated by Prof. Cope and by him pronounced to be decidedly dinosaurian and therefore indicative of Cretaceous age. On the other hand, the fossil plants from the same beds have been studied by Prof. Lesquereux, who informs me that they are unquestionably Tertiary types. My own investigations having been confined to the invertebrates, it is of these chiefly that I will speak here. In the first place, it will be seen that all of these yet known belong to a few genera of mollusks, represented by 12 or 14 species. And just here it may be stated that, although partly committed in favor of the opinion that this formation belongs to the Cretaceous and still provisionally viewing it as most probably such, I do not wish to disguise or conceal the fact that the evidence favoring this conclusion to be derived from the mollusks alone, as now known, is by no means strong or convincing. The genera are probably all common both to the Cretaceous and Tertiary, as well as to the present epoch. * * * The entire absence among the fossils yet known from this formation of *Baculites*, *Scaphites*, *Ancyloceras*, *Phychoceras*, *Ammonites*, *Gyrodes*, *Inoceramus*, and all of the other long list of genera characteristic of the Cretaceous or in part also extending into older rocks, certainly leaves its molluscan fauna with a strong Tertiary facies. * * * It thus becomes manifest that the paleontological evidence bearing on the question of the age of this formation, so far as yet known, is of a very conflicting nature; though aside from the dinosaurian, the organic remains favor the conclusion that it is Tertiary.

It is plain that Meek was very much confused by the data then available, especially by the invertebrates, for he declared in another place that they might with almost equal propriety be referred to the Tertiary or the Cretaceous, and as the vertebrate evidence was interpreted to mean undoubted Cretaceous, only the fossil plants were left to sustain unfalteringly the Tertiary side of the argument. It was immediately pointed out, as it is occasionally even to the present day, that the error made by Oswald Heer in referring plants of the Dakota "group" to the Miocene[33] weakened the evidence of fossil plants and gave added weight to the dictum of the vertebrate paleontologist, namely, that the presence of dinosaurian reptiles in a formation was positive proof of Cretaceous age. Thus Cope was so firmly convinced that the presence of *Agathaumas* at Black Buttes proved the Cretaceous age of the "Bitter Creek series" that in 1874 he proceeded to refer the "Great Lignitic" of the upper Missouri to the same period. In discussing the age of certain vertebrate-bearing beds in northern Colorado, he said:[34]

> Believing, as I do, that the evidence derived from the vertebrate remains requires the reference of the Bitter Creek coal series to the Cretaceous period, and having pointed out on similar grounds that the horizon of the Great Lignite from which vertebrate remains have been procured on the Missouri River is undoubtedly Mesozoic, although usually regarded as Tertiary, I suspect that the corresponding strata in Colorado will be found to pertain to the same section of geologic time.

In another bulletin of this series Cope[35] had an extensive article on the fossil vertebrates then recognized from the Cretaceous of the West. In this paper vertebrates from the localities on Moreau River and between Moreau and Grand rivers, S. Dak.; at Long Lake, N. Dak.; north of Big Horn River, Mont.; and in Colorado, now mainly referred to the Lance formation, he for the first time definitely referred to the Cretaceous. In alluding to the studies of the flora of these beds by Lesquereux and Newberry, he said (p. 16):

> They have, as is well known, pronounced this whole series of formations as of Tertiary age, and some of the beds to be as high as Miocene. The material on which this determination is based is abundant, and the latter must be accepted as demonstrated beyond all doubt. I regard the evidence derived from the mollusks in the lower beds, the vertebrates in the higher, as equally conclusive that the beds are of Cretaceous age. There is, then, no alternative but to accept the result, *that a Tertiary flora was contemporaneous with a Cretaceous fauna, establishing an uninterrupted succession of life* across what is generally regarded as one of the greatest breaks in geologic time.

The above statement by Cope has often been quoted during the 48 years since it was written, and it is only recently that its converse—that is, that a fauna of Cretaceous type may be contemporaneous with a Tertiary flora—has been admitted as even possible.

This conclusion was further elaborated by Cope in Hayden's annual report for 1873, in a paper that was more or less in the nature of a reply to the article by Newberry already mentioned. In the same report Marvine[36] had an elaborate paper on the results of his studies in Middle Park, Colo., in which he considered among many other things, the age of the lignite-bearing formations of Colorado. After alluding to the weakness of the invertebrate evidence for the Cretaceous age and the apparent strength of the evidence derived from the terrestrial vertebrates, he said:

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[33] Those who are interested in this reference of the Dakota sandstone to the Miocene may be instructed by reading Lesquereux's account of the conditions under which the error was made (U. S. Geol. Survey Terr. Sixth Ann. Rept., for 1872, p. 343, 1873). From this account it appears that Heer never saw specimens of the Dakota plants, for only outline drawings of a few species were submitted to him. They were mostly dicotyledonous leaves and wholly unlike any then (1857) known from the Cretaceous of Europe, and the drawings were without the essential details of nervation. As soon as the specimens themselves were seen by Newberry he recognized their correct characters.

[34] Cope, E. D., Report on the stratigraphy and Pliocene vertebrate paleontology of northern Colorado: U. S. Geol. and Geog. Survey Terr. Bull. [1st ser.], No. 1, p. 10, 1874.

[35] Cope, E. D., Review of the Vertebrata of the Cretaceous period found west of the Mississippi River: U. S. Geol. and Geog. Survey Terr. Bull. [1st ser.], No. 2, pp. 1-81, 1874.

> It must be supposed, then, that either a Cretaceous fauna extended forward into the Eocene period and existed contemporaneously with an Eocene flora, or else that a flora, wonderfully prophetic of Eocene times, anticipated its age and flourished in the Cretaceous period to the exclusion of all Cretaceous plant forms. * * * In either case the fact remains that here the physical and other conditions were such that one of the great kingdoms of life, in its progress of development, either lost or gained upon the other, thus destroying relations and associations which existed between them in those regions from which were derived the first ideas of life boundaries of geologic time, causing here apparent anomalies.

As a probable explanation of these apparent discrepancies, Marvine wisely concludes as follows: "Much of the confusion and discrepancy has, in my opinion, arisen from regarding different horizons as one and the same thing."

In his report for 1873 Lesquereux had a further paper on the "Lignitic" flora in which he of course argued still more strongly for its Tertiary age. He also revised the several "groups" into which he divided the section of lignite-bearing rocks and presented full lists of the species of plants found in each.

In Hayden's original description of the Fort Union formation he predicted that it would be found extending into Canadian territory, and this prediction was verified in 1874 by George M. Dawson,[37] who published an article in which he accepted the views of Hayden and Lesquereux and referred the Fort Union to the Eocene. In discussing the views of Cope he said:

> The evidence does not appear to show that the Cretaceous species were of themselves becoming rapidly extinct, but that over the western region, now forming part of this continent, the physical conditions changing drove the Cretaceous marine animals to other regions, and it is impossible at present to tell how long they may have endured in oceanic areas in other parts of the world. This being so, and in view of the evidence of the preponderant animal and vegetable forms, it seems reasonable to take the well-marked base of the Lignite series as that of the lowest Tertiary, at least at present. The formation described belongs to this lowest Tertiary, being, in fact, an extension of Hayden's Fort Union group, and from analogy may be called Eocene.

The work upon which Dawson's views were based was done in connection with the British North American Boundary Commission, of which he was geologist. In a report of progress for 1873, published in 1874, he affirmed his original statement in the following language:[38]

> The formation is, however, undoubtedly an extension of the Great Lignite or Fort Union group of strata of Hayden, as developed in the Western States and Territories. * * * These strata immediately succeeding the Cretaceous rocks are the lowest American representatives of the Tertiary series and have been called, for this reason, Eocene.

In the final report of the Boundary Commission, published in 1875, the same views were expressed.

About this time John J. Stevenson, who was then associated with the Wheeler Survey, published a number of papers on the geology of portions of Colorado and New Mexico in which he argued strongly for the Cretaceous age of the lignite-bearing beds, especially along the Front Range. In a chapter on the age of the Colorado lignites[39] he reviewed the opinions of Hayden, Lesquereux, and others and concluded that the presence of the supposed fucoid *Halymenites major* was an indication of Cretaceous rather than Eocene age, as advocated by Lesquereux. Subsequent study has shown that Stevenson was correct in referring the beds containing *Halymenites* to the Upper Cretaceous, but he failed to note the presence of the profound unconformity that has since been demonstrated by Whitman Cross and W. T. Lee to occur in the midst of this supposedly continuous coal-bearing section.

In the annual report of the Hayden Survey for 1874, published in 1876, there are three very important papers dealing more or less completely with this subject. The first of these is one by Hayden, in which he summed up his understanding of the lignite group at that date. He gave a brief history of the group and pointed out that the evidence for its age, as interpreted by different geologists and paleontologists, is very conflicting. He said:

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[36] Marvine, A. R., Report of the Middle Park division: U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1873, p. 107, 1874.

[37] Dawson, G. M., The Lignite formations of the West: Canadian Naturalist, vol. 7, p. 241, 1874.

[38] Dawson, G. M., Report on the Tertiary Lignite formation in the vicinity of the 49th parallel, British North Am. Boundary Com., 1874.

[39] U. S. Geog. and Geol. Surveys W. 100th Mer. Rept., vol. 3, pp. 404-410, 1875.

> One fruitful source of difference of opinion has been in the misunderstanding in regard to the different horizons of coal strata of the West. That there are important coal beds in rocks of well-defined Cretaceous age can not be disputed, and I have long since yielded that point. What we wish to show more clearly is that there exists in the West a distinct series of strata which we have called the Lignite group, and that it is entirely separate, paleontologically and geologically, from a great group of strata in the lower Cretaceous, and perhaps extending down into the Jurassic, which contains a great number of thick and valuable beds of coal. It is not necessary to discuss the question whether the term Lignitic shall be applied to the coal of either or both groups. I have used the term Lignitic for the upper group without reference to the quality of its fuel, simply to distinguish it from the other great groups of older date, the ages of which are not questioned.

From the above statement it is clear that Hayden was entirely willing to admit the existence of coal in the Cretaceous of the Rocky Mountain region, and from this it of course followed that the term "Lignitic" was not applicable to all the coal-bearing strata; in fact, he distinctly stated that the term was to be applied only to the upper coal-bearing séries. He still argued, however, for the connection of the coal-bearing beds of the Laramie Plains and Colorado with the vast group to the northwest.

The same report contained a long paper by A. C. Peale on the geology of portions of Colorado, in which he presented a series of tables illustrating the progress of opinion regarding the "Lignitic group." He discussed the different opinions at length and reached the following conclusions:

> 1. The lignite-bearing beds east of the mountains in Colorado are the equivalent of the Fort Union group of the upper Missouri and are Eocene Tertiary; also, that the lower part of the group, at least at the locality 200 miles east of the mountains, is the equivalent of a part of the lignitic strata of Wyoming.
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> 2. The Judith River beds have their equivalent along the eastern edge of the mountains below the Lignite or Fort Union group and also in Wyoming and are Cretaceous, although of a higher horizon than the coal-bearing strata of Coalville and Bear River, Utah. They form either the upper part of the Fox Hills group (No. 5) or a group to be called No. 6.

Also in this report for 1873 Lesquereux had an extensive paper under the title "On the Tertiary flora of the North American Lignitic, considered as evidence of the age of the formation." He again took up the objections that had been urged against his interpretation and answered each in detail as the evidence appeared to him. His opinion remained unchanged.

The historical review of opinion which preceded the introduction of the term Laramie has now been presented in sufficient detail to make clear the necessity for a convenient, usable, common appellation. Those who had approached the subject from a study of the northern areas—that is, of the upper Missouri River region and contiguous territory—were naturally impressed with the strength of the argument for the Tertiary age of the lignite-bearing beds, while those who had first become familiar with the more southern areas were quite as strongly of the opinion that the beds they studied were of Cretaceous age. Subsequent study has shown that both these views contained a measure of truth.

As A. C. Peale was at that time actively engaged in geologic work in the Rocky Mountain area, his recollection of the conditions then current, as set forth in a recent article,[40] is of interest:

> As a member of the Hayden Geological Survey at the time the term "Laramie" was first proposed and used by both the Hayden and King organizations, and as one of those who first used it, a statement of my recollection may be of some interest here. Just at the time the work of the Exploration of the Fortieth Parallel, under Clarence King, was approaching completion, and their geologic maps were being colored, the work of the United States Geological and Geographical Survey of the Territories had also reached the stage when it became necessary to color the maps of Colorado, upon which field work was begun in 1873 and finished in 1876. As two of the maps of the former organization adjoined the work of the Hayden Survey along the northern line of Colorado, it was deemed desirable that there should be some correlation, in terms at least, where the work joined. There was substantial agreement as to most of the formations, about the only difference being as to the age of the beds resting conformably upon the Fox Hills Cretaceous of Hayden as exposed along the line of the Union Pacific Railway and to the westward of the foothills of the Front Range of Colorado, where they were usually designated by Hayden and the members of his Survey as the Lignitic beds of eastern Colorado or the lignitic coal group of the eastern slope. These beds were considered by King to be of Cretaceous age, while Hayden was inclined to consider them as belonging to the Tertiary. At this time Clarence King wrote to Dr. Hayden asking him to propose a name for these debatable beds—debatable only as to age, for both agreed as to their stratigraphic position. In reply to this letter Hayden suggested the name Laramie, which was accepted by King, as indicated by him on page 331

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[40] Peale, A. C., On the application of the term Laramie: Am. Jour. Sci., 4th ser., vol. 27, p. 45, July, 1909.

> of the volume on systematic geology,[41] where he says: "During the slow gathering of the evidence which shall finally turn the scale I proposed to Dr. Hayden that we adopt a common name for the group and that each should refer it to whatever age his data directed. Accordingly, it was amicably agreed between us that this series should receive the group name of Laramie and that it should be held to include that series of beds which conformably overlies the Fox Hills."

It may be of interest to point out that, so far as now known, the word Laramie used as a geologic formational term first appeared in an author's proof of geologic map No. II of the Fortieth Parallel Survey, by Clarence King and S. F. Emmons. This map was dated November 15, 1875, and was noticed in the American Journal of Science for February, 1876, but in neither place was there any definition of the term. The first printed description of the Laramie was apparently that given by Arnold Hague[42] in volume 2 of the final reports of the Fortieth Parallel Survey, in which he presented a very small and relatively unimportant section that claims distinction only on the ground that it was the first section ever published of the Laramie. It was measured on the Denver Pacific Railroad 5 or 6 miles west of Carr station and about 18 miles southeast of Cheyenne, Wyo. Peale[43] stated that "this section, if any should be so considered, would be the typical Laramie section."

Hayden first used the term Laramie in an article published in 1877.[44] In this article he followed the coloring on King's map above mentioned, which he undoubtedly had before him at the time.

King and the members of his Survey frankly and, as he says, "cheerfully" adopted the classification and nomenclature of the Upper Cretaceous section as defined by Hayden. After describing the Cretaceous rocks of their area up to and including the Fox Hills, King said:[45]

> Here, with those who follow Hayden, the Cretaceous series comes to an end. Conformably over this (Fox Hill) lies the group which Hayden and I have agreed to call the Laramie, which is his Lignitic group and is considered by him as a transition member, between Cretaceous and Tertiary. There is no difference between us as to the conformity of the Laramie group with the underlying Fox Hill. It is simply a question of determination of age upon which we differ.

King was in error, however, in stating that the Laramie was the equivalent of Hayden's Fort Union "group," or indeed that it included all of the so-called Lignitic, and it was undoubtedly the assumption by subsequent writers that this was so that led to much of the discussion and difference of opinion that speedily arose. Hayden's last published word on this point[46] occurs in the letter transmitting Lesquereux's "Tertiary flora" to the Secretary of the Interior and is as follows:

> If objection is made to the use of the term "Lignitic" group, I would say that in this work it is restricted to a series of coal-bearing strata lying above the Fox Hills group, or Upper Cretaceous, and these are embraced in the divisions Laramie and Fort Union groups. It is well known that there are in various parts of the West, especially along the fortieth parallel and southwestward, very thick beds of coal in the various divisions of the Cretaceous, extending down even into the upper Jurassic. Had this not been the case, the more general term Lignitic would not have been retained by the Survey in preference to any other.

On the succeeding page of this letter he summed up his conclusion in the following words:

> The facts as we understand them at the present time would seem to warrant this general division, viz, a marine series, Cretaceous; gradually passing up into a brackish-water series, Laramie; gradually passing up into a purely fresh-water series, Wasatch. It is also probable that the brackish-water beds on the upper Missouri must be correlated with the Laramie, and that the Wasatch group as now defined and the Fort Union group are identical as a whole, or in part at least.

The Laramie was by that time fairly launched, and the literature devoted to it became increasingly voluminous and scattered. It is not possible nor perhaps desirable in the present connection to follow all the intricate ramifications of the discussion, and only an outline of the salient features will be attempted. The two points that attracted most attention were the areal distribution of the Laramie and of course its age. As so frequently happens in discussions of this kind, the pendulum when once started was permitted to swing too far, with the result that beds were included in the Laramie that subsequent study has proved have little or no intimate connection with this formation, at least on the basis of the original definition by King. Some phases of this history will be set forth in the following pages.

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[41] U. S. Geol. Expl. 40th Par. Rept., vol. 1, 1878.

[42] Idem, vol. 2, pp. 60, 61, 1877.

[43] Am. Jour. Sci., 4th ser., vol. 27, p. 49, 1909.

[44] Notes on some artesian borings along the line of the Union Pacific Railroad in Wyoming Territory: U. S. Geol. and Geog. Survey Terr. Bull., vol. 3, pp. 181-185, April 5, 1877.

[45] U. S. Geol. Expl. 40th Par. Rept., vol. 1, p. 348, 1878.

[46] U. S. Geol. Survey Terr. Rept., vol. 7, p. iv, 1878.

One of the first to take up the study of the Laramie from both the geologic and the paleontologic sides was Charles A. White. In the first paper in which he employed the term Laramie [47] the use was relatively unimportant and the term was not defined. He gave two generalized sections—one of the Green River region, in which he placed the Laramie in its proper position between the Fox Hills and the Wasatch beds, and within the larger grouping of post-Cretaceous, which also includes the lower part of the Wasatch; and the other of the upper Missouri River region, in which the Laramie was not included but its place was taken by the Judith River "group," while the post-Cretaceous was made to include this and a portion of the overlying Fort Union.

White's reasons for regarding the Laramie as post-Cretaceous were set forth in the fifth of his "Paleontological papers" [48] published in the same volume as the paper just cited. He said that all who had examined the fossils from the Dakota, Colorado, and Fox Hills deposits as they are developed in southern Wyoming and adjacent parts of Utah and Colorado, whether vertebrate or invertebrate, would not question their Cretaceous age. The fossils of the Green River and Bridger strata were said to disclose equally conclusive evidence of their Tertiary age. He went on to say that the two groups of beds between the Fox Hills below and the Green River above are the Laramie and Wasatch, and that somewhere within these vertical limits must come the line between Cretaceous and Tertiary. He then continued:

> With a few doubtful exceptions, none of the strata of the Laramie group were deposited in open-sea waters; and with equally few exceptions, none have yet furnished invertebrate fossils that indicate the Cretaceous rather than the Tertiary age of the group. * * * Again, the brackish and fresh water types of Mollusca that are afforded by the Laramie and the lower portions of the Wasatch group are in most cases remarkably similar, and some of the species of each group respectively approach each other so nearly in their characteristics that it is often difficult to say in what respect they materially differ. Moreover, they give the same uncertain indication as to their geological age that all fossils of fresh and brackish water origin are known to do.
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> It is in view of the facts here stated, and also because I believe that a proper interpretation of them shows the strata of the Laramie group and the base of the Wasatch to be of later date than any others that have hitherto been referred to the Cretaceous, and also earlier than the Eocene epoch, that I have decided to designate those strata as post-Cretaceous, at least provisionally.

In the annual report of the Hayden Survey for 1876, published in 1878, White presented in a lengthy paper the results of his field studies in Colorado for the years 1876 and 1877. He still retained the term post-Cretaceous for the Laramie and in an instructive table (p. 22) showed that he regarded it as the equivalent of the Laramie of King, the Point of Rocks group of Powell, and the Lignitic of Hayden. He defined it as follows:

> The fact that this series passes insensibly into the Fox Hills group below and into the Wasatch group above renders it difficult to fix upon a stratigraphical plane of demarcation, either for its base or summit. I have therefore decided to regard this group as essentially a brackish-water one, referring all strata below that contain any marine Cretaceous invertebrate forms to the Fox Hills group, beginning this series with those strata that concontain brackish and fresh water forms, and ending it above with those strata in which the brackish-water forms finally cease. Thus defined, the whole series seems to form one natural paleontological group, as well as to be a sufficiently distinct stratigraphical one, for which I have adopted the name of Laramie group of King.

The term post-Cretaceous was also employed by Endlich [49] in his report on the White River area of Colorado, and by Peale [50] in his work in the Grand (now Colorado) River region.

The application of the term Laramie was carried farther and farther afield, until ultimately it was made to include a vast area in the Rocky Mountain region. When the term was first proposed by King no type locality was mentioned but it was expressly stated to include the lignite-bearing beds lying conformably above the Fox Hills along the Front Range in northern Colorado and along the west side of the range in eastern and central Wyoming. The term was immediately accepted, though with reservations as to the age represented, by the members of the Hayden

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[47] Catalogue of the invertebrate fossils hitherto published from the fresh and brackish water deposits of the western portion of North America: U. S. Geol. and Geog. Survey Terr. Bull., vol. 3, pp. 607-614, May 15, 1877.

[48] Idem, pp. 625-629.

[49] U. S. Geol. and Geog. Survey Terr. Tenth Ann. Rept., for 1876, pp. 77, 109, 1878.

[50] Idem, p. 181.

Survey, who extended its application to western Colorado and adjacent areas. After the death of Meek the mantle of invertebrate paleontologic work fell largely upon the shoulders of C. A. White, and he had a large part in extending the application of the Laramie. In the seventh of his "Paleontological papers"[51] he gave the following range for Laramie as he then accepted it:

> The term Laramie group is here used to include all the strata between the Fox Hills group of the Cretaceous period beneath and the Wasatch group (=Vermillion Creek group of King) of the Tertiary above. That is, it includes, as either subordinate groups or regional divisions, both the Judith River and Fort Union series of the upper Missouri River; the Lignitic series east of the Rocky Mountains in Colorado; the Bitter Creek series of southern Wyoming and the adjacent parts of Colorado; and also the "Bear River Estuary beds," together with the Evanston coal series, of the valley of Bear River and adjacent parts of Utah. Strata of this great Laramie group are known to exist in other large and widely separated districts of the western portion of the national domain.

Later the Laramie was believed by White to have been recognized as far south as the States of Chihuahua, Coahuila, and Nuevo Leon, in northern Mexico. It was also adopted by the Canadian geologists and shown by them to extend over a vast area in the British possessions. In fact, as late as 1891, after a number of important horizons had been removed from the confines of the Laramie, White[52] gave the following as the recognized distribution of the formation:

> The present geographical outlines of the area within which strata of this formation occur are not yet well known, but it apparently is as great as that within which any other North American formation has been observed. Their presence has been recognized at so many and such widely separated localities that they safely may be assumed to once have formed a continuous deposit from near the twenty-sixth to near the fifty-fifth parallel of north latitude and in certain districts from near the one hundred and third to near the one hundred and fifteenth meridian. That is, it is evident that this formation originally consisted of a continuous deposit nearly or quite 2,000 miles long from north to south, and more than 500 miles across from east to west.

The structural and lithologic character of the Laramie as it was then (1891) accepted was well set forth by White,[53] who wrote as follows:

> In lithological character the Laramie formation is remarkably uniform throughout both its geographical and vertical extent, and it seems everywhere to have been the result of continuous sedimentation from base to top. Its strata within the whole of the great area which they occupy are mostly composed of sandy material, but frequently they are more or less argillaceous and rarely calcareous. Sandstones of much firmness often occur among them, but a large part of the sandy strata are soft and friable. Shaly strata not infrequently occur, and these are often carbonaceous. The formation throughout its whole extent is coal-bearing.

The question concerning the Laramie which gave rise to the most extensive discussion and difference of opinion was, of course, that of its age. It may be of interest to present a brief recapitulation of the divergent views on this point that had been promulgated up to about 1890, or approximately to the time when, if it is permissible to use the expression, the reaction set in, and the pendulum began its backward swing as regards what should or should not be included within the limits of this formation—the point that subsequent investigation has shown is the cause of much of this difference of opinion.

King and the other members of the Fortieth Parallel Survey regarded the Laramie as of Cretaceous age and the equivalent of the Lignitic group of Hayden. The term was immediately accepted by Hayden and the members of the Survey under his direction, though not wholly as a substitute for the earlier "Lignitic," for they admitted undoubted Cretaceous coals. Hayden regarded the Laramie as transitional between Cretaceous and Tertiary. Endlich, from his studies in the vicinity of Trinidad, Colo., referred the coal-bearing rocks of the region (=Laramie) to post-Cretaceous or pre-Tertiary. White, Endlich, and Peale, who investigated the Laramie, especially in Utah, Wyoming, and Colorado, called it post-Cretaceous, and White in particular stated his belief that it was transitional between Cretaceous and Tertiary. Stevenson and Newberry also were familiar with the areas in southern Colorado and New Mexico and were firm in their belief that it was Cretaceous. The vertebrate paleontologists Cope, Marsh, and many others after them referred the Laramie unqualifiedly to the Cretaceous, largely on the ground that it contained remains of dinosaurian reptiles that were believed to be an unfailing mark of Cretaceous age. On the other hand, Lesquereux, from his extensive studies of the fossil plants, was strenuous in his claim that the "Lignitic" and later the Laramie were of Tertiary age.

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[51] White, C. A., On the distribution of molluscan species in the Laramie group: U. S. Geol. and Geog. Survey Terr. Bull., vol. 4, No. 3, p. 721, July 29, 1878.

[52] White, C. A., Correlation papers—Cretaceous: U. S. Geol. Survey Bull. 82, p. 145, 1891.

[53] Idem, p. 146.

In 1884–85 Lester F. Ward[54] instituted an elaborate investigation and comparison of the fossil plants, in the hope of throwing conclusive light on its age. Ward was undoubtedly influenced by the prevailing opinion, chiefly that of White, as to what should be regarded as Laramie, with the result, as is now known, of referring to it beds later proved to belong to the Montana, Laramie, Arapahoe, Denver, Lance, and Fort Union, and it is small wonder that he was unable to reach definite conclusions.

From this point on it will be inexpedient to follow the strictly chronologic method of treatment, for the reason that the literature is so very extensive and scattered, and consequently it will be taken up by regions or special horizons that have, for one reason or another, come into prominence. Each of these, particularly those of special interest as bearing on the problem, will be followed through to the present time. It is to be remembered that the area over which the Laramie was believed to be more or less continuously exposed reached its maximum extension about 1890, since when, by a process of elimination or subtraction, it has constantly been diminishing until at the present time only a comparatively small area remains to support the name.

RELATIONS BETWEEN THE LARAMIE OF THE DENVER BASIN, TAKEN AS A STANDARD, AND THE REPORTED LARAMIE IN THAT AND OTHER AREAS.

As set forth in the preceding pages, the history of the Laramie formation shows that it has had what may be called a rise and fall. From the date of the introduction of the term into geologic literature and usage, in 1875, to about 1890 its application was undergoing a process of expansion, until the formation was believed to have covered a vast area extending from northern Mexico to the Arctic Circle and many hundreds of miles in width. In part concurrent with this expansion, or from about 1888 to the present time, the application of the term has been subjected to a process of elimination or curtailment, until, as was long ago so aptly stated, the problem became not so much "To what age does the Laramie belong?" as "What belongs to the Laramie?"

As time went on, it was again and again incontestably shown that beds supposed to fulfill the requirements of the definition of the Laramie had been incorrectly so placed for one reason or another, and reasonable doubt had been cast upon the right of many other beds to be considered as typical Laramie.

It is proposed in the following pages to review the several stratigraphic units or geographic areas to which or within which the term Laramie is no longer considered applicable or at least requires a greater or less measure of qualification. So far as possible the sequence is chronologic, but naturally it has not been expedient to adhere strictly to the chronologic order, so far as that would lead to needless repetition or to the breaking up of the discussion of a natural geographic unit. Nevertheless, it has been impossible to avoid some repetition and overlapping in the treatment, owing to the fact that results obtained in one field may have a more or less important bearing on another field.

ARAPAHOE AND DENVER FORMATIONS.

The area about the city of Denver, Colo., now well known as the Denver Basin, is in a way classic ground for geology. It had been visited and studied in greater or less detail by a number of geologists and paleontologists, including J. L. LeConte, F. V. Hayden, Leo Lesquereux, A. R. Marvine, C. A. White, S. F. Emmons, Whitman Cross, G. H. Eldridge, and L. F. Ward. The coal-bearing rocks conformably above the marine Cretaceous Fox Hills formation were at first believed to be a southern extension of the "Lignitic group" of the upper Missouri River region and were held by Hayden, Lesquereux, and others to be of Tertiary age. When the Laramie "group" was established by King, this portion of the section in the Denver Basin and adjacent areas along the Front Range fell within its limits, and the beds were regarded by him and by those who accepted his views as Cretaceous. This so-called Laramie was for many years regarded as a unit, notwithstanding the fact that at certain points along the base of the mountains, notably at Golden, the lower or coal-bearing portion of the section was vertical, whereas the adjacent beds of Table Mountain were practically horizontal. Some geologists invoked the presence of a hypothetical fault to account for this obvious discordance, but it is now known to be due to a sharp fold and not to a fault. This is shown by the fact that at Green Mountain, 3 or 4 miles south of Golden, the Arapahoe and the lower part of the Denver, as well as the Laramie, are vertical. Both the lower and the upper beds are abundantly plant-bearing, and both had furnished extensive collections, but, as it later appeared, no distinction was made in the specimens or in the records concerning them, all being called simply "Laramie," with the result that when the horizons were proved to be distinct, the greatest confusion and difficulty arose in the effort to separate them.

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[54] Ward, L. F., Synopsis of the flora of the Laramie group: U. S. Geol. Survey Sixth Ann. Rept., for 1884-85, pp. 401-557, 1886.

As early as the summer of 1881, when Whitman Cross [55] began his studies in the Denver Basin, he "first observed," to use his own language, "that the Table Mountain strata possessed characteristics proving them to belong to a series distinct from the normal Laramie." No published announcement of this discovery was made at the time, and field work was continued in the region for a number of succeeding years, during which G. H. Eldridge ascertained that another distinct Tertiary formation occurred between that discovered by Cross and the normal Laramie. A preliminary statement of the most important results of this investigation was made by Eldridge and Cross in two papers read before the Colorado Scientific Society July 2, 1888. In the first of these papers[56] Eldridge named and described the Arapahoe formation,[57] which, he stated, was "the formation next succeeding the Laramie in geological order and unconformably resting on it." It was characterized as follows:

> It is composed of a basal member of conglomerate or gritty sandstone, according to its distance from the foothills, with an overlying zone of gray argillaceous or arenaceous shales, containing lenticular masses of hard, quartzose sandstone, with an occasional ironstone; when confined between under- and overlying groups it has a thickness varying between 600 and 1,200 feet.

In the succeeding paper Cross [58] named and described the Denver Tertiary formation, which he found to be unconformably overlying the Arapahoe. Lithologically it was found to be composed almost entirely of andesitic volcanic material; its thickness was given as 800 to 1,200 feet.

As already indicated, both Arapahoe and Denver were regarded originally as of Tertiary age and both were found to contain fairly abundant vertebrate remains belonging to turtles, crocodiles, dinosaurs, and, it was at first supposed, mammals. These remains were studied by O. C. Marsh, and at first the study resulted in great confusion. The dinosaurs from the Denver were pronounced to be "typical Jurassic dinosaurs of both herbivorous and carnivorous types." [59] Though found in the same beds, what was described as a bison was referred to latest Pliocene time. Later these dinosaurs and the supposed bison were found to belong to the Ceratopsidae, a group of horned dinosaurs especially abundant in Converse County, Wyo., to which consideration will be given in subsequent pages. This determination, according to the vertebrate paleontologists, fixed their age as Cretaceous. The invertebrates consisted of a few rather poorly preserved fresh-water types that did not prove of much value in fixing the age.

Fossil plants were abundant, especially in the Denver beds, but, as already stated, the specimens collected were not labeled with the names of specific localities, and all were regarded as of Laramie age. Before they could be utilized in the light of this newer information as regards their stratigraphic relations, it was necessary to separate them on the basis of the matrix. They were fortunately preserved in the United States National Museum, and a study of the matrix undertaken by Cross resulted in showing that they were abundantly distinct from those of the underlying Laramie—in fact, out of about 98 species in the Laramie and some 140 in the Arapahoe and Denver, only about 15 nominal species were found in common. Subsequent studies of the Arapahoe and Denver plants have shown them to be essentially Tertiary in type.

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[55] Cross, Whitman, The Tertiary Denver formation: Am. Jour. Sci., 3d ser., vol. 37, p. 262, 1889.

[56] Eldridge, G. H., On some stratigraphical and structural features of the country about Denver, Colo.: Colorado Sci. Soc. Proc., vol. 3, pp. 86–118, 1888.

[57] This was first named the "Willow Creek beds," but on the ground of preoccupation the name was changed in a footnote (p. 97) to Arapahoe.

[58] Cross, Whitman, The Denver Tertiary formation: Colorado Sci. Soc. Proc., vol. 3, pp. 119–133, 1888. Recast and republished under the same title in Am. Jour. Sci., 3d ser., vol. 27, pp. 261–282, 1889.

[59] Cannon, G. L., On the Tertiary Dinosauria found in Denver beds: Colorado Sci. Soc. Proc., vol. 3, p. 143, 1888.

In 1892 Cross[60] briefly reviewed the relations of the Arapahoe and Denver formations of the Denver Basin and also enumerated additional localities in the Huerfano Basin, Gunnison County, the Yampa River region, the Animas River region, Middle Park, and elsewhere, in which identical or similar stratigraphic relations had been suggested. He discussed at length the conflicting paleontologic evidence of the age of the lake-bed deposits and concluded as follows:

> The writer wishes to advocate the restriction of the term Laramie, in accordance with its original definition, to the series of conformable beds succeeding the marine Montana Cretaceous, and the grouping of the post-Laramie lake beds described, with their demonstrated equivalents, in another series to which a comprehensive name shall eventually be given. * * * The question as to whether the series shall be referred to the Cretaceous or to the Eocene can not be finally settled until the various conflicting elements of the evidence have been adjusted on a basis of further and more exact information.

Later in the same year Cross[61] published an article on the post-Laramie beds of Middle Park, as an amplification of the previous brief notice. In this article he showed that the large area referred to the "Lignite" or Laramie was occupied by a thick series of mainly andesitic rock resting unconformably on marine Cretaceous beds, with no evidence that the Laramie had ever been present. These beds, which he called the Middle Park beds, were correlated with the Denver on account of the lithologic similarity and the identity of the contained flora.

The publication of the Denver Basin monograph by Emmons, Cross, and Eldridge[62] was delayed until 1896, and in many ways the delay was perhaps of advantage, for it permitted the incorporation and discussion of many important facts that had in the meantime been made available regarding the stratigraphic and other relations of the determined or supposed correlatives of the formations here under discussion. The Laramie, Arapahoe, and Denver formations of the Denver Basin were, of course, described in detail, and the unconformable relations between the Laramie and overlying Arapahoe were especially made plain. The magnitude of the time interval represented by the unconformity was insisted upon as of major importance in Rocky Mountain geology.

The Arapahoe and Denver formations were in this monograph referred to the Cretaceous out of deference to the views of the vertebrate paleontologists, as it had been found that the vertebrates appeared to be much more nearly allied to Mesozoic than to Cenozoic types. The lithologic and stratigraphic relations of these formations, as well as a very full discussion of the several lines of paleontologic evidence, are given by Cross, who prepared this portion of the volume. In the light of subsequent development it has been found that many of his queries and adumbrations have had a wide and increasingly important application.

For ten years after the publication of the Denver Basin monograph little active work was prosecuted in this region, though investigations in adjacent or more remote areas were found to have a more or less direct bearing on the problem here involved. In 1907 A. C. Veatch,[63] from studies in Carbon County, Wyo., was led to question the validity of the current application of the term Laramie. He endeavored to prove that Carbon, Wyo., was intended by King to be the type locality for the Laramie. In this vicinity Veatch discovered that in the supposedly continuous Laramie section there is a profound unconformity similar to that found by Cross in the Denver Basin, and as the beds at Carbon studied and described by the members of the King Survey are all above this break he contended that the name should properly be applied only to these beds and not to the beds that are conformable to the Cretaceous section. Veatch further held that the delimitation of the Arapahoe and Denver constituted a virtual redefinition of the Laramie.

Replies to this paper were made by Cross[64] and Peale,[65] and it is sufficient to state that the view advocated by Veatch has not been adopted. Cross especially reviewed the facts relating to the application of the term, hold-ing that the separation of the Arapahoe and Denver did not constitute redefinition, and finally, following a suggestion made by himself in 1892, proposed for the latter and their equivalents the term Shoshone group. He said:

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[60] Cross, Whitman, Post-Laramie deposits of Colorado: Am. Jour. Sci., 3d ser., vol. 44, pp. 19-42, 1892.

[61] Cross, Whitman, Colorado Sci. Soc. Proc., vol. 4, pp. 192-213, 1892.

[62] U. S. Geol. Survey Mon. 27, 1896.

[63] On the origin and definition of the geologic term Laramie: Am. Jour. Sci., 4th ser., vol. 24, p. 18, 1907; expanded under the same title in Jour. Geology, vol. 15, p. 526, 1907.

[64] Cross, Whitman, The Laramie formation as the Shoshone group: Washington Acad. Sci. Proc., vol. 11, pp. 27-45, 1909.

[65] Peale, A. C., On the application of the term Laramie: Am. Jour. Sci., 4th ser., vol. 28, pp. 45-58, 1909.

> It is proposed to apply the term Shoshone group to the deposits which unconformably succeed the Laramie and to their equivalents and which are overlain by the Fort Union or Wasatch beds when they are present.

In this paper Cross reviewed briefly the data bearing on the age of these post-Laramie beds and concluded as follows:

> In the preceding discussion I have avoided the question as to the age of Shoshone beds, whether Cretaceous or Eocene. I desire now to urge their reference to the Eocene. The Denver beds were originally referred by me to the Eocene, but the great weight attached to the Mesozoic affinities of the vertebrate fauna by paleontologists led to a tentative acquiescence in the assignment of the Arapahoe and Denver formations to the Cretaceous in the Denver monograph.

RATON MESA REGION OF COLORADO AND NEW MEXICO.

In 1907 a series of observations were begun in the Raton Mesa region of southern Colorado and northern New Mexico, which were found ultimately to have an important bearing on the formations under discussion in the Denver Basin.

The Canon City field of Colorado, although slightly extralimital, is here included in the Raton Mesa region, which really begins with Walsenburg, Colo., and vicinity and extends southward to Cimarron River, N. Mex. The early history of geologic exploration and interpretation in this region has already been given in the historical review of the time which preceded the establishment of the term Laramie, and in this connection it is only necessary to mention the names of Le Conte, Lesquereux, Hayden, Newberry, and Stevenson as among those who took principal parts in the discussion. The section of coal-bearing rocks in this region was considered by one set of students as being more or less directly the equivalent of the "Lignite group" of the north and Tertiary in age. The opposing students regarded the age as Cretaceous, but when the Laramie was established by King the definition appeared to fit the Raton Mesa section, and consequently the beds in this area soon came to be accepted as of Laramie (Cretaceous) age. It should not be overlooked, however, that from his studies of the fossil plants Lesquereux was led to insist that the flora of certain localities within this area, notably Raton Pass and Fishers Peak, indicated a correlation with the so-called "Eolignitic" (=Wilcox formation) of the Gulf region and was of Tertiary age.

A critically annotated historical review of geologic and paleontologic literature on this region is given in a recent paper by Lee and Knowlton,[66] to which the reader is referred for full particulars. In the present connection it is sufficient to begin with the time—about 1900—when geologists had reached a general agreement that the coal-bearing rocks of the Raton Mesa region are of Laramie age and, moreover, that sedimentation had been continuous and uninterrupted throughout the deposition of this section. Thus, in my "Catalogue of the Cretaceous and Tertiary plants of North America,"[67] published in 1898, the plants from the Raton region were referred to the Laramie as then currently accepted. In Newberry's long delayed monograph on the later extinct floras of North America,[68] also issued in 1898, the few species from this region were referred without question to the Laramie. In the Walsenburg and Spanish Peaks geologic folios, by R. C. Hills,[69] issued in 1900 and 1901, respectively, the productive coal measures were referred to the Laramie without qualification.

In 1909, however, W. T. Lee[70] published a short paper under the title "Unconformity in the so-called Laramie of the Raton coal field, New Mexico," in which the following was given as the thesis:

> The purpose of this paper is to describe an unconformity hitherto unknown that is of more than ordinary interest because it divides rocks previously referred to the Laramie into two distinct formations. * * * During the time interval represented by the unconformity the sedimentary rocks previously laid down within the Raton field were subjected to erosion for a considerable length of time, and the Rocky Mountains west of this field were elevated and eroded to a depth of several thousand feet.

Lee further pointed out that

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[66] Lee, W. T., and Knowlton, F. H., Geology and paleontology of the Raton Mesa and other regions in Colorado and New Mexico: U. S. Geol. Survey Prof. Paper 101, pp. 17-37, 1918.

[67] Knowlton, F. H., U. S. Geol. Survey Bull. 152, 1898.

[68] Newberry, J. S., U. S. Geol. Survey Mon. 35, 1898.

[69] Hills, R. C., U. S. Geol. Survey Geol. Atlas, Walsenburg folio (No. 68), 1900; Spanish Peaks folio (No. 71), 1901.

[70] Lee, W. T., Geol. Soc. America Bull., vol. 20, pp. 357-358, 1909.

> The upper formation has the stratigraphic position of the Arapahoe of the Denver Basin but contains a flora apparently more closely related to that of the Denver formation than it is to the Laramie of the Denver Basin. The lower one has the stratigraphic position of the Laramie of the Denver Basin but contains a flora that is apparently older than Laramie.

As regards the significance of this unconformity Lee added:

> There are several possibilities of interpretation, as will be pointed out in the following pages, but the one considered most probable is that the uplift and erosion represented by the unconformity were contemporaneous with the post-Laramie uplift and erosion described by Cross and others from the Denver region.

Without unduly anticipating, it may be stated that subsequent work has entirely confirmed this interpretation.

In 1910 G. B. Richardson,[71] in a short report on the coal resources of the Trinidad coal field of Colorado, noted the conglomerate described by Lee in the report on the Raton coal field as marking the unconformity and said:

> The significance of the conglomerate in the Trinidad field remains to be determined. Occurring intermittently in the midst of coal-bearing rocks, it may represent only a local change in conditions of deposition, or, as maintained by Lee for a conglomerate in the Raton field, presumably the same as the one just described, it may mark an unconformity contemporaneous with the post-Laramie unconformity of the Denver Basin. * * * The final word concerning the age of the rocks above and below this conglomerate in the coal measures, involving its significance as a hiatus marker, must come from the paleontologist.

As the paleobotanic data then tentatively supplied by me were more or less conflicting and inconclusive, Richardson wisely enough concluded that

> Until further paleobotanical knowledge is available, the age of these rocks must remain unsettled. For the present it seems best to retain the old nomenclature and to refer the strata occurring between the Trinidad sandstone and the Poison Canyon formation to the Laramie.

In the same volume with Richardson's report is a paper by C. W. Washburne [72] on the Canon City coal field, Colo., in which he stated that

> The Laramie formation, which contains all the coal beds of the Canon City field, rests conformably on the Trinidad sandstone and is unconformably overlain by the Arapahoe (?) conglomerate. The productive division of the formation is the lower 600 or 700 feet.

Although Washburne admitted that the "upper part of the coal measures contains a flora equivalent to that of the Laranie formation of the Denver Basin, while the lower part contains a flora of upper Montana age," he concluded that "there seems no good reason for separating these lower beds from the Laramie, even though they contain an upper Montana flora."

The work on the stratigraphy and paleobotany of this region was continued by Lee and Knowlton,[73] and their results were presented for publication early in 1913. These results I briefly summed up in May of that year as follows:[74]

> In 1907 W. T. Lee began the study of the coal in the Raton field, and while prosecuting this work he discovered the presence of an unconformity in the midst of the section of coal-bearing, supposed Laramie rocks. This unconformity was traced throughout the entire Raton Mesa and subsequently was carried around the southern end of the mountains and well up along their western front. The rocks below the unconformity, to which the name Vermejo formation has been given, have a maximum thickness of only about 375 feet, while the rocks above the unconformity, now called the Raton formation, are about 1,600 feet in thickness. In some places the Raton formation rests on the full thickness of the Vermejo formation, while in other localities the Vermejo is greatly reduced, and in at least one place the entire Vermejo, together with the underlying Trinidad sandstone, has been removed and the Raton rests directly on Pierre.
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> When the unconformity had been demonstrated, it became of the greatest interest and importance that the fossil plants should be studied to ascertain their bearing, first, on the distinctness of these two formations, and, second, on the question of age. * * * The total flora of the Raton Mesa region comprises 257 forms, of which number 106 belong to the lower, or Vermejo and Trinidad formations, and 151 to the upper, or Raton formations. Only 4 species have been found to cross the line of the unconformity, which is taken as pretty conclusive evidence of the distinctness of the two formations. * * * The Vermejo formation is shown by the plants to be Cretaceous (Montana) in age, being in the approximate position of the Mesaverde.
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> The Raton formation is shown to be essentially of the same geologic age as the Denver formation of the Denver Basin and of the Wilcox formation of the Gulf region, the latter being indisputably of Eocene age. The conclusion is therefore reached that the Raton and Denver formations are Eocene in age.

In the meantime, as indicated above, Lee had continued the studies from Raton Mesa around the south end of the Rocky Mountains and well up along the west side. His results were set forth in a paper published in 1912.[75]

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[71] Richardson, G. B., The Trinidad coal field, Colo.: U. S. Geol. Survey Bull. 381, pp. 379–446, 1910.

[72] U. S. Geol. Survey Bull. 381. pp. 341–378, 1910.

[73] Lee, W. T., and Knowlton, F. H., Geology and paleontology of the Raton Mesa and other regions in Colorado and New Mexico: U. S. Geol. Survey Prof. Paper 101, 1918.

[74] Knowlton, F. H., Results of a paleobotanical study of the coal-bearing rocks of the Raton Mesa region of Colorado and New Mexico; Am. Jour. Sci., 4th ser., vol. 35, pp. 526–530, 1913.

COLORADO SPRINGS AREA.

Although the Colorado Springs area is in practical connection with the Denver Basin and in fact is considered a part of the basin in the present study, there are reasons that make it desirable to treat this area separately and specifically.

The first fairly comprehensive account of the geology of this area was given in 1869, by F. V. Hayden,[76] who made a reconnaissance study from Cheyenne, Wyo., through the Denver Basin, Colorado Springs, Canon City, and Raton fields. At that time he considered the coal-bearing rocks as belonging to the "Lignitic" and of Tertiary age.

In 1872 Leo Lesquereux [77] visited this region and gave a brief account of the geologic relations of the coal-bearing rocks, including a section of the rocks at the Gehrung coal mine, north of Colorado Springs, which he considered as similar to the section in the Raton Mountains. A list of the fossil plants collected is given on page 375 of his report.

In the following year A. C. Peale [78] also gave a short account of the geology of the Colorado Springs area, but it was mainly a confirmation of the work of Lesquereux, whose section at the Gehrung mine he quoted. Peale also visited the Franceville coal mines, about 12 miles east of Colorado Springs, and identified portions of the section with that at the Gehrung mine. The fossil plants he obtained at this locality are enumerated on pages 326–375 of his report.

At this point it is necessary to speak of the so-called Monument Creek group, on account of the part it played in the elucidation of the geologic history of this region. The term "Monument Creek group" was established by Hayden [79] for a series of "variegated beds of sands and arenaceous clays, nearly horizontal, resting on the upturned edges of the older rocks, * * * of various colors * * * and of various degrees of texture." This series occurs along the Front Range on the divide between the Platte and Arkansas drainage, where it covers an area "of about 40 miles in width from east to west, and 50 miles in length north and south." From its modern appearance Hayden concluded that it was of "either late Miocene or Pliocene age."

In 1873 Cope [80] referred to the "Monument Creek" as follows:

> The age of the Monument Creek formation in relation to the other Tertiaries not having been definitely determined, I sought for vertebrate fossils. The most characteristic one I procured was the hind leg and foot of an artiodactyl of the *Oreodon* type, which indicated conclusively that the formation is newer than the Eocene. From the same neighborhood and stratum, as I have every reason for believing, the fragment of the *Megaceratops* [obvious error for *Megacerops*] *coloradoensis* was obtained. This fossil is equally conclusive against the Pliocene age of the formation, so that it may be referred to the Miocene until further discoveries enable us to be more exact.

In the following year (1874) Hayden [81] again referred to the "Monument Creek group." After describing it at some length, and alluding to Cope's statement regarding the vertebrate evidence, he said: "As to the real age of this group, I am inclined to regard it as Miocene, perhaps upper Miocene."

The next publication that it is necessary to notice is the Denver Basin monograph,[82] by Emmons, Cross, and Eldridge, though in that work the discussion of these rocks was brief, as they occur in the series of beds mapped only as projecting tongues forming the divide between the Platte and Arkansas waters. Emmons gave first a brief summary (p. 38) in which, although calling the beds the "Monument Creek formation," he noted that "two divisions have been distinguished, marked by an apparent unconformity and period of erosion." The lower division was referred tentatively to the Miocene on the basis of the previous vertebrate work of Cope, while the upper division was thought probably to be referable to the Pliocene.

Eldridge devoted several pages to a general description of the stratigraphic relations, lithology, and life of the "Monument Creek formation," which was of course the basis for the general statement by Emmons. Concerning the stratigraphic relations Eldridge said:

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[75] Lee, W. T., Stratigraphy of the coal fields of northern central New Mexico: Geol. Soc. America Bull., vol. 23, pp. 571–686, 1912. As already indicated, the complete report on the Raton Mesa region by Lee and Knowlton was published in 1918 as U. S. Geol. Survey Prof. Paper 101; to this report the reader is referred for details of the geology and paleobotany.

[76] Preliminary field report of the United States geological survey of Colorado and New Mexico, pp. 37–46, 1869; reprint, pp. 137–146, 1873.

[77] The Lignitic formation and its fossil flora: U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1872, pp. 325–327, 1873.

[78] Peale, A. C., U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1873, pp. 202–203, 1874.

[79] Op. cit., p. 40.

[80] Cope, E. D., Report on the vertebrate paleontology of Colorado: U. S. Geol. and Geog. Survey Terr. Ann Rept. for 1873, p. 430, 1874.

[81] Hayden, F. V., U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1874, pp. 36, 37, 1876.

[82] Emmons, S. F., Cross, Whitman, and Eldridge, G. H., U. S. Geol. Survey Mon. 27, pp. 38, 39, 252–254, 1896.

> The Monument Creek formation occurs along the southern edge of the Denver field in the steep slopes of a high mesa and also stretches from its base prairieward in thin sheets. The floor of the lake in which the Monument Creek was deposited was more or less irregular from erosion and in one part or another consisted of the clays and sandstones of the Laramie, Arapahoe, or Denver formations. In the foothill region the Monument Creek lies in contact with the Arapahoe; between Platte River and Cherry Creek a few hundred feet of Denver beds exist, which further to the east disappear. North and east of Coal Creek, on the eastern edge of the field, both Denver and Arapahoe are wanting and the Monument Creek rests directly upon the clays of the Laramie.

Although the relations between the Arapahoe and Denver and the "Monument Creek" were somewhat obscure, the interpretation naturally followed that the latter was structurally above the former, for it was then supposed that the lower division of the "Monument Creek" was of Miocene age, while the Arapahoe and Denver were referred to the Cretaceous.

In 1902 W. T. Lee[83] discussed at some length the "Monument Creek group" of Hayden. To the lower portion (of Emmons and others) he applied the name "Monument Creek formation" and described it as "composed of conglomerates, breccias, sands, and clays which alternate and intermingle and grade into each other in the most lawless manner." Continuing, Lee said:

> Above the Monument Creek beds lie masses of rhyolitic tuff. This tuff has been noted by Hayden and others. It forms more or less of a sheet, or sheets in some places, while in others it occurs intermingled with sand, gravel, and clay. * * * Above the tuff occurs a sheet of glassy rhyolite about 25 feet thick which forms the protecting cap of several of the buttes near Castle Rock.

To the "youngest formation in the Castle Rock region" Lee gave the name "Castle conglomerate." This was the "Upper Monument Creek" of Hayden and the so-called upper division of Emmons and others. Concerning it Lee said:

> These upper beds differ in character from those of the lower division; they are separated from it by volcanic tuffs and flows of rhyolite and by an unconformity representing a period of erosion, as shown by the presence in it of the material from the underlying rhyolite. It is therefore separate and distinct from the lower division.

Lee did not procure data bearing on the age of the divisions of the "Monument Creek" recognized by him, but three years later N. H. Darton[84] obtained additional vertebrate evidence as regards the upper division. At a number of localities he collected remains of *Titanotherium* and *Hyracodon*, concerning which he wrote as follows:

> All this material appears to have been obtained from the upper beds and it correlates these beds with the Chadron formation of the White River group, or Oligocene. No evidence was obtained as to the age of the lower member. * * * The presence of the unconformity between the upper and lower members suggests that the latter may be of Wasatch or Bridger age. The nearest locality to the Monument Creek area at which Oligocene deposits occur in eastern Colorado is in the vicinity of Akron and Fremont's Butte, where *Titanotherium* remains occur in abundance.

The status of the "Monument Creek" problem remained as above indicated until 1910–11, when G. B. Richardson began a study of this region preparatory to the preparation of a report on the geology of the Castle Rock quadrangle, which is joined by the Denver Basin on the north and by the Colorado Springs quadrangle on the south. As a result of this study Richardson[85] stated that he found it necessary to separate the "Monument Creek group" into two formations on the basis of a well-marked unconformity which separates beds of Eocene and Oligocene age. The lower formation was named the Dawson arkose and the upper one the Castle Rock conglomerate. According to Richardson the stratigraphic relations indicate that the Arapahoe and Denver formations are equivalent to the lower part of the Dawson arkose, and this evidence is paleontologically supported.

The Castle Rock conglomerate may be first considered. This formation is the "Upper Monument Creek" of Hayden and others, the so-called "upper division of the Monument Creek" of Emmons, Eldridge, Darton, and others, and the Castle conglomerate of Lee.[86] It occurs in the south-central part of the Denver Basin, where it crops out in detached areas on the divides between the tributaries of South Platte River from a point near Elbert to the vicinity of Sedalia, a distance of about 40 miles.

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[83] The areal geology of the Castle Rock region, Colo.: Am. Geologist, vol. 29, pp. 101-103, 1902.

[84] Age of the Monument Creek formation: Am. Jour. Sci., 4th ser., vol. 20, pp. 178-180, 1905.

[85] Richardson, G. B., The Monument Creek group: Geol. Soc. America Bull., vol. 23, pp. 267-276, 1912.

[86] Lee's name was unavailable on account of prior usage.

It is thus a remnant of a once larger formation that has been reduced by erosion. Concerning its stratigraphic relations Richardson said:

> Everywhere the Castle Rock conglomerate rests on an undulating surface of the underlying Dawson arkose, and there is an abrupt change in texture of the material from the medium or fine grained arkose of the upper part of the Dawson to the coarse Castle Rock conglomerate.

Richardson procured additional vertebrate remains from the Castle Rock conglomerate, which were identified by J. W. Gidley, of the United States National Museum, as *Titanotherium*, and the correlation of these beds with the Chadron formation, the lower formation of the Oligocene White River group, was thus confirmed.

More interest attaches to the Dawson arkose—that is, the lower division of the "Monument Creek group"—for its exact age had long been in doubt. It has a maximum thickness of about 2,000 feet on the west, toward its source in the mountains, and is thinner toward the east. Its appearance was described by Richardson as follows:

> The formation is a complex aggregate of varicolored and varitextured conglomerate, sandstone, shale, and clay, derived from the rocks of the Front Range and deposited under a variety of continental conditions. They are medium to coarse textured arkosic grits, composed chiefly of quartz and feldspar derived from the Pikes Peak granite and associated rocks. * * * Rhyolitic rocks * * * were extravasated on an uneven surface of arkose in the extreme upper part of the Dawson. * * * The stratigraphic relations of the Dawson arkose to the Denver and Arapahoe formations * * * are generally concealed by a cover of Quaternary deposits, so that actual conditions are obscure. It is not claimed for the recent work that final correlations have been established, but nevertheles previously unsuspected relationships are indicated.
>
> Approaching the geologically mapped part of the Denver Basin from the south, where detailed work had not previously been done, it was found that the lower part of the Dawson arkose seems to pass along the strike into the Arapahoe and Denver formations; that the Dawson and Arapahoe can not be separated lithologically, even at the type locality of the Arapahoe, on the bluffs of Willow Creek; and that the Denver and Dawson apparently merge into each other, or interdigitate, layers of arkose typical of the Dawson being found intercalated in andesitic Denver material. These conditions indicate that the Arapahoe and Denver are equivalent to the lower part of the Dawson arkose. The marked difference in lithology between the andesitic Denver and the arkosic Dawson may be accounted for by the geographic distribution of the rocks which supplied the sediments.

The paleontologic support of the age determination of the Dawson arkose consists of a number of collections of fossil plants, which are pronounced to be of undoubted Denver age, and a single bone of a mammal, which was identified by Gidley as that of a creodont and of which he said: "From our present knowledge of the creodonts such a type could not be older than Wasatch." Although no dinosaurs were found by Richardson in the Dawson arkose, he referred to their occurrence, as reported by Marsh, in Monument Park, 8 miles north of Colorado Springs, in beds that must belong to the Dawson. Ceratopsian dinosaurs have been found in the Arapahoe and Denver formations, but not thus far in the Laramie of the Denver Basin.

In 1912, however, Lee[87] visited the locality where the creodont bone above mentioned was found (Jimmy Camp Creek, 9 miles east of Colorado Springs) and there collected the remains of turtles and of dinosaurs. The turtles were examined by O. P. Hay and the dinosaurs by C. W. Gilmore. Mr. Gilmore reported on these bones as follows:

> The collection consists of fragmentary ceratopsian bones none of which is sufficiently characteristic to determine the genus to which it belongs, and one ungual phalanx is doubtfully regarded as belonging to the dinosaur *Trachodon*. Two small shell fragments show the presence of hard and soft shell turtles. Of these Dr. Hay says: "The soft shell resembles those of the Lance formation; the other resembles those of the Wasatch but is too fragmentary to be certain of its affinities."

In commenting on the above statements Lee wrote:

> We have then at this locality, near Colorado Springs, in beds that lie unconformably on the Laramie, a flora that correlates these beds with undoubted Eocene on the one hand, and on the other with the Denver and Arapahoe formations; a mammal of a type not known heretofore to be older than Wasatch; a turtle whose nearest known allies are in the Wasatch fauna; another that resembles those of the Lance fauna; and dinosaurs that have been somewhat generally regarded as indicative of Cretaceous age but which occur in associations that convince some geologists that they are Tertiary. Considering this association of fossils in connection with the great unconformity, it seems wholly irrational longer to regard a formation as Cretaceous merely because it contains dinosaurs.

We may now return to the more direct consideration of the Laramie of the Colorado Springs region. In 1908 M. I. Goldman[88] spent some months in the investigation of the coal resources of this area, and after describing briefly the Pierre shale and Fox Hills sandstone, he wrote as follows concerning the Laramie:

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[87] Lee, W. T., Recent discovery of dinosaurs in the Tertiary: Am. Jour. Sci., 4th ser., vol. 35, pp. 531-534, 1913.

[88] The Colorado Springs coal field, Colo.: U. S. Geol. Survey Bull 381, pp. 317-340, 1910.

> Above the Fox Hills sandstone lie the coal-bearing rocks of Laramie age. These may be divided into two members—a lower including several massive sandstone beds and three or more of the most important coal beds of the field, and an upper composed of clay shale, sandy shale, and some sandstone with poorly developed coal beds.
>
> The best exposure of the sandy, coal-bearing member is in Popes Bluff, where the base of the formation is composed of a massive sandstone from 40 to 100 feet thick but not sharply defined from the underlying Fox Hill. The upper part of the sandstone member of the Laramie gives way gradually, toward the east, to shale with thin beds of calcareous and ferruginous sandstone about 250 feet thick. In the western part of the field the sandy member is about 200 feet thick.

Owing to the incompleteness of the paleontologic evidence, mainly that of fossil plants, Goldman did not make definite age determinations for the rocks above the Laramie, which were described under the terms "conglomerate," "andesitic material," and "arkose," in ascending order.

In some parts of the field the shaly part of the Laramie is overlain by a conglomerate, which has a maximum known thickness of about 30 feet. "The lithologic similarity of this bed to some parts of the Arapahoe formation in the Denver Basin is apparent."

At a number of localities the conglomerate is overlain by beds of andesitic material, "which in lithologic composition is similar to the Denver formation." The average thickness of the beds of andesitic material is about 125 feet.

> Beds of arkose lie unconformably upon the andesitic material and overlap the coal-bearing sandstone in the southeast corner of sec. 6, T. 13 S., R. 67 W. The arkose has two phases—(1) coarse arkose near the mountains, some sandstone, and clay containing coarse quartz grains; (2) fine-grained, very micaceous sandstone. Both phases are very irregularly bedded, and most of the lithologic units are of small horizontal extent.

The greatest thickness of arkose measured was 300 to 400 feet in Corral Bluffs, but the total thickness was believed to be still greater.

A number of collections of fossil plants made in the immediate Colorado Springs area by A. C. Peale, M. I. Goldman, and others were submitted to me for study at this time (1908). This material was not well preserved, owing to the friable nature of much of the matrix, and it was studied with difficulty. With the material available I was not then able to differentiate the three formational units—Laramie, Arapahoe, and Denver—that were theoretically inferred to be present; in fact, the Laramie elements appeared to preponderate so greatly that I was inclined to refer all the plant collections to the Laramie. On bringing together in a single list all the forms enumerated in these collections, as well as those reported originally by Lesquereux from the Gehrung mine and Franceville—both in the acknowledged Laramie—it was found that a total of 49 forms were represented. Of these 22 were not specifically determined, leaving 27 named species, most of which were known outside the Colorado Springs area. On analysis, it appeared that 19 of these forms were found in Laramie or older beds, but, as will be pointed out later, nearly all of these are found in the lots which belong to the Laramie and about which there is no question. There was one lot, however, collected high in the section of the bluffs just west of Templeton Gap that as then identified did much to influence my reference of these beds to the Laramie. As originally listed this lot contained the following forms:

Sequoia brevifolia Heer.
Sequoia longifolia Lesquereux.
Dammara sp. cf. D. acicularis.
Salix? sp., fragment.
Ficus trinervis Knowlton, fragment.
Rhamnus salicifolius Lesquereux.
Cyperacites sp.
Viburnum? sp.
Carpites sp. (poor).

At the time these identifications were made the "Monument Creek group" was supposed to be of Oligocene age, and it was deemed absolutely impossible that these plant remains could be of this age; in fact, if they were correctly identified and stood alone, there would ordinarily be no hesitation in referring them to the Laramie, which I did. Since that time, however, I have twice visited this region and collected material from this locality, as well as from neighboring localities of similar stratigraphic position, and I have also collected material and studied several collections made some 20 miles or more to the east, out on the plains, with the result that I have acquired a better understanding of the forms represented and their stratigraphic relations.

A number of the species of plants from the Pulpit Rock area are the same as those occurring at Black Buttes, Wyo., in beds which were then supposed to be in the Laramie but which in my opinion subsequent work has shown pretty conclusively to be of post-Laramie age. This naturally makes a difference in the weight given to Laramie position. Furthermore, as already stated, much of the material from Pulpit Rock and vicinity is very fragmentary and difficult to identify satisfactorily, but in the light of the material obtained farther east it becomes clearer, and this has permitted certain revisions of earlier determinations. Below are the lists from Templeton Gap and vicinity; the first one is a revision of the one given above:

Bluffs west of Templeton Gap:
  Sequoia obovata? Knowlton ined.
  Sequoia acuminata Lesquereux.
  Dammara sp.
  Cyperacites sp.
  Salix sp.
  Ficus trinervis Knowlton.
  Rhamnus salicifolius Lesquereux.
  Carpites sp. (Palmocarpon?).
Palmer's ranch, Templeton Gap, 4 miles northeast of Colorado Springs:
  Carpites sp.
  Sequoia sp.?
Palmer's ranch, half a mile farther west:
  Rhamnus salicifolius? Lesquereux.
  Platanus? sp.
  Viburnum sp., probably new.

These lots may be considered together. Of the four named species, two (*Sequoia acuminata* and *Ficus trinervis*) were described originally from specimens obtained at Black Buttes, Wyo.; the other two are survivals from the Laramie or older. Of these the *Rhamnus* is well known as crossing the line between Cretaceous and Tertiary, but the *Sequoia* had not previously been recognized as doing this. The *Sequoia*, however, is represented only by a single rather poorly preserved branchlet and may not be correctly determined. The *Dammara* is apparently an undescribed form; it is Cretaceous in type, though the genus is still living.

The several localities above mentioned as lying out on the plains to the east and northeast of Colorado Springs may now be considered. It is a well-known fact that the Laramie, as well as certain overlying beds. stands at acute angles in many places near the mountains, but within a few miles the dips rapidly diminish and the beds become nearly horizontal. The country becomes grass covered, rock exposures are few and far between, and sections showing the contacts of the formational units are still fewer. It is especially difficult to establish satisfactorily the line between the Laramie and the overlying beds in this plains region, and recourse must be had to paleontology in the allocation of the more or less isolated localities.

A number of plant collections have been made at these uncertain points in the section. According to Richardson, by whom most of these collections were made, the plant-bearing beds are 1,000 feet or more, as determined by drill records, above the Fox Hills, and between 20 and 150 feet below a bed of conglomerate that marks the base of a thick deposit of coarse-grained light-colored arkose which is lithologically quite distinct from the underlying fine-grained drab and buff-colored plant-bearing sandstones and shales resembling the typical Laramie. It is suggested by Richardson, on stratigraphic grounds, as a possibility worth considering that these leaves come from a horizon high in the Laramie, approximately equivalent to the Scranton coal zone 15 miles east of Denver, from which few leaves have heretofore been collected.

Below are the lists of plants from the localities mentioned:

Near Mosby, Colo., 30 feet above coal:
  Flabellaria? sp., fragmentary.
  Pteris undulata Lesquereux.
  Anemia.
  Equisetum sp.
  Ficus denveriana? Cockerell.
  Laurus socialis Lesquereux.
  Laurus wardiana? Knowlton.
  Viburnum marginatum? Lesquereux.
  Sapindus sp.
One-fourth mile east of Purdon's mine, Colo.:
  Platanus haydenii Newberry.
  Nelumbo? new, fine.
  Hedera sp., new, fine.
  Populus nebrascensis Newberry.
  Ficus sp.?
  Sapindus sp.?
Red Hill, 4 miles south of Ramah, Colo.:
  Platanus raynoldsii Newberry.
  Vitis olriki Heer.
  Cissus lobato-crenata Lesquereux.
  Myrica? sp.?
NW. ¼ sec. 30, T. 9 S., R. 60 W., 50 feet below conglomerate:
  Platanus sp. cf. P. haydenii?
  Platanus rhomboidea Lesquereux.
  Populus sp.?

- 2½ miles southwest of Norton, Colo.:
  - Platanus sp.
  - Ficus denveriana Cockerell.
  - Populus sp.
  - Hicoria antiquora? (Newberry) Hollick.
  - Palm rays, gen.?
  - Salix angusta? Alex. Braun.
  - Ficus denveriana Cockerell.
  - Populus sp.?
  - Magnolia?
  - Laurus? sp., fragments.
  - Fraxinus eocenica Lesquereux.
- Half a mile southeast of Ramah oil prospect, Colo.:
  - Lygodium kaulfusii Heer.
  - Anemia lanceolata Knowlton.
  - Myrica like M. torreyi, but without teeth.
  - Ficus sp. cf. F. denveriana Cockerell.
  - Laurus sp.
  - Populus sp. cf. P. nebrascensis Newberry.

On bringing the named forms together we have the following list:

Pteris undulata.
Lygodium kaulfusii.
Anemia.
Hicoria antiquora?
Salix angusta?
Populus nebrascensis.
Ficus planicostata.
Ficus denveriana.
Platanus haydenii.
Platanus raynoldsii.
Platanus rhomboidea.
Vitis olriki.
Cissus lobato-crenata.
Laurus socialis.
Laurus wardiana?
Magnolia?
Fraxinus eocenica?
Viburnum marginatum.

As this list stands, and on the assumption that the determinations have been correctly made, no one familiar with the several floras of the Denver Basin would hesitate, I think, to pronounce this a distinctly post-Laramie flora. If we eliminate the six species of which the identification is questioned and confine attention to positively determined forms, it follows that only two species from this list—*Ficus planicostata* and *F. denveriana*—have been admitted into the Laramie flora as set forth in the present work. As may be seen by consulting the description (p. 131), *Ficus planicostata* is a wide-ranging form that occurs in the Montana, Laramie, Wilcox, and Denver formations and the beds at Black Buttes, Wyo., while *F. denveriana* (see p. 138) is essentially a Denver species, and the evidence of its presence in the Laramie consists of a single more or less imperfect leaf from Popes Bluff, near Colorado Springs, the identification of which is properly questioned.

A further analysis might be made of the forms not specifically named in the above lists; but this is not deemed necessary, as it can be confidently asserted that their affinities undoubtedly lie with post-Laramie rather than with Laramie species.

It will thus be seen that, as now understood, the plants do not lend support to the suggestion that these beds are of Laramie age, and they have not been included in the present work. If it should ultimately be shown that these horizons are really in the upper part of the Laramie and not in post-Laramie beds, such a result would help to break down the marked distinction now believed to exist between the flora of the Laramie and that of overlying beds, but this is a contingency which the writer is not now prepared to recognize.[89]

LANCE FORMATION.

The age and proper allocation of what is now very generally known as the Lance formation has been one of the most active of the storm centers about which the Laramie controversy has been waged. As viewed in retrospect, it appears that much of the discordance that arose was due to the varying weight attached to the several available kinds of paleontologic criteria, as will be made plain in the following exposition.

The most marked or conspicuous paleontologic characteristic of the Lance formation is undoubtedly the presence of the huge dinosaurian reptiles that have been found in it at so many localities, and it is beyond question that this characteristic did much to direct and stimulate investigation of the formation, which might otherwise have been long delayed.

The first collection of remains of the group of horned dinosaurs known as the Ceratopsia was made by F. V. Hayden in the vicinity of Judith River, Mont., about 1855, but the distinctive characters of the group were not discovered until more than 30 years later. The material collected by Hayden, consisting of isolated teeth, was described by Joseph Leidy, who tentatively regarded it as of Jurassic (Wealden) age. A fuller discussion of the Judith River problem will be found on page 77.

The next in order of discovery was the celebrated *Agathaumas sylvestris* Cope, found in

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[89] Since the foregoing pages were written it has been demonstrated by Lee that the Scranton coal and the beds at a number of localities on Sand Creek and Coal Creek, east of Denver, are of post-Laramie age. This determination has an important bearing on the age of the beds east of Colorado Springs mentioned in this chapter. The discovery made by Lee is explained on page 103.

1872 at Black Buttes, Wyo., by F. B. Meek, and later in the same year collected by Cope himself. (See p. 8.) In the following year Cope[90] found the remains of what is now known to be a member of this group at some unidentified locality in Colorado, and in 1876 he undertook the exploration of the Judith River region, describing a number of remains that from their fragmentary nature he was not able to allocate until the group had been made better known from the studies of O. C. Marsh.

As already mentioned (p. 16), the remains of horned dinosaurs, although not at first so recognized, were found by Lakes, Cross, Eldridge, Cannon, and others in the post-Laramie beds of the Denver Basin of Colorado during the period extending from 1881 to about 1887. These were described in part by Marsh. In the summer of 1888 J. B. Hatcher, then assistant to Marsh, found the poorly preserved remains of a dinosaurian in Wyoming just north of the Seminoe Mountains, on the west side of North Platte River about 40 miles below Fort Steele.

The above brief account completes the list of discoveries of remains of the Ceratopsia that fall within the present discussion prior to the finding of the celebrated deposits in Converse County, Wyo. These deposits were made known late in the fall of 1888, when a single horn core was brought to the attention of Mr. Hatcher by a resident of the region. This discovery was considered so important by Marsh that Hatcher was directed to return to the region at the earliest moment, which was in January, 1889, and from this time until 1895 Hatcher was almost continuously employed in exploring and collecting from these rich deposits. The material he obtained, which was very extensive and varied, furnished the basis for a series of important papers by Marsh.

Before proceeding to the discussion of the Converse County area and its bearing on the question under consideration, it may be well to point out that the family Ceratopsidae, which has become so important in this connection, was established by Marsh[91] in December, 1888. The exact locality that yielded the specimen on which this family was based was not recorded by Marsh, who said it "was found in place, in Laramie deposits of the Cretaceous, in Montana," and added in the next paragraph: "Remains of the same reptile, or one nearly allied, had previously been found in Colorado, in deposits of about the same age." According to Hatcher[92] the beds of the Montana locality were near the top of the Judith River formation on Cow Creek, 10 miles above its confluence with the Missouri. The Colorado specimen referred to came from the Arapahoe formation of the Denver Basin.[93]

Marsh's first paper[94] dealing with what is now known to be the Converse County material was published in April, 1889, and describes some Jurassic forms and a single specimen from this region. This was named *Ceratops horridus*, and in August of the same year it was made the type of the genus *Triceratops*.[95] Incidentally it may be mentioned that this genus was based in part on the horn core first known from these beds as noted by Hatcher. In neither of these papers is there mention of the locality beyond the statement that the remains came from "the Laramie formation of Wyoming."

In December, 1889, a third paper by Marsh[96] was published, in which, in addition to describing the skull more in detail, he gave the following brief statement on the geologic occurrence of the Ceratopsidae:

> The geological horizon of these strange reptiles is a distinct one in the upper Cretaceous and has now been traced nearly 800 miles along the eastern flank of the Rocky Mountains. It is marked almost everywhere by remains of these reptiles, and hence the strata containing them may be called the *Ceratops* beds. They are fresh-water or brackish deposits, which form a part of the so-called Laramie but are below the uppermost beds referred to that group. In some places, at least, they rest upon marine beds which contain invertebrate fossils characteristic of the Fox Hills deposits.

In commenting on this statement a few years later, Cross[97] said:

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[90] Cope, E. D., Report on the vertebrate paleontology of Colorado: U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1873, p. 429, 1874.

[91] Marsh, O. C., A new family of horned Dinosauria, from the Cretaceous: Am. Jour. Sci., 3d ser., vol. 36, p. 478, 1888.

[92] Hatcher, J. B., The Ceratopsia: U. S. Geol. Survey Mon. 49, p. 101, 1907.

[93] Cross, Whitman, Geology of the Denver Basin of Colorado: U. S. Geol. Survey Mon. 27, p. 230, 1896.

[94] Marsh, O. C., Notice of new American Dinosauria: Am. Jour. Sci., 3d ser., vol. 37, p. 331, 1889.

[95] Marsh, O. C., Notice of gigantic horned Dinosauria from the Cretaceous: Am. Jour. Sci., 3d ser., vol. 38, p. 173, 1889.

[96] Marsh, O. C., The skull of the gigantic Ceratopsidae: Am. Jour. Sci., 3d ser., vol. 38, pp. 501-506, 1889.

[97] Cross, Whitman, Geology of the Denver Basin of Colorado: U. S. Geol. Survey Mon. 27, p. 231, 1896.

> The statement that "a distinct horizon" has been "traced nearly 800 miles" and that "it is marked everywhere" by certain fossils would imply either that actual continuity had been proved or that the stratigraphic position of the fossil-bearing strata had been found to be clearly the same at numerous localities not far apart. But when Prof. Marsh made the above assertion the Denver region was the only one in which the position of the *Ceratops*-bearing beds had been established in complete sections, and here they were found to be separated from the typical Laramie below them by a great stratigraphic break. Moreover, none of the described fossils was found east of the mountains between the Denver Basin and Converse County, Wyo., a distance of 200 miles. As far, then, as the new fossils themselves are concerned, they prove either a great extension of the Arapahoe and Denver (post-Laramie of this report), or a distribution of the fossils in question beyond the limits of what may be properly termed one formation or horizon.

In the following paragraph Cross added:

> In the original description by Prof. Marsh the fossils were said to have been obtained in "the Laramie of Wyoming" or "the *Ceratops* beds of Wyoming." It is important to emphasize the fact that not one of the described species came from the typical Laramie strata of southern Wyoming or from their demonstrated equivalent.

In succeeding years Marsh[98] continued to publish short papers on the Converse County material, but without a definite indication of locality, the only statement being that the fossils were "from the Laramie" or "from the *Ceratops* beds of Wyoming." In February, 1893, however, Hatcher[99] published a short paper, in which, for the first time, complete and definite information was given as to the locality at which this wonderful vertebrate fauna had been found, as well as a description of the lithologic character and stratigraphic occurrence of the beds containing it, and also the reasons for regarding the horizon as referable to the true Laramie.

The typical area for the "*Ceratops* beds," which have since become classic, was stated to be in the northeastern portion of Converse County, now included in Niobrara County, which lies on the eastern border of Wyoming. These beds were also found in adjacent portions of Weston County. In his description of the deposits Hatcher said:

> The *Ceratops* beds are made up of alternating sandstones, shales, and lignites, with occasional local deposits of limestones and marls. The different strata of the series are not always continuous, a stratum of sandstone giving place to one of shales, and vice versa. This is generally true of the upper two thirds of the beds. * * * The shales are quite soft and loosely compacted, composed mostly of clay with more or less sand in places. The prevailing color is dark brown, but they are sometimes red or bluish. * * * The lignites occur in thin seams, never more than a few inches thick, of only limited extent, and with many impurities. * * * All the deposits of the "*Ceratops* beds" of this region bear evidence of having been laid down in fresh waters. Among the invertebrate fossils found in them, only fresh-water forms are known. There is no evidence that marine or brackish waters have ever had access to this region since the recession of the former at the close of the Fox Hills period.

As regards the stratigraphic position of the "*Ceratops* beds," Hatcher stated that the lowest exposed member of the section was identified by its numerous invertebrates as Pierre. Overlying this was an alternating series of sandstones and shales having an estimated thickness of 500 feet and containing, especially in the upper portion, an abundant invertebrate fauna pronounced to be typically Fox Hills. Above this series came the "*Ceratops* beds," which had an estimated thickness of 3,000 feet. He added:

> All the beds of the entire section are conformable and bear evidence of a continuous deposition, from the Fort Pierre shales up through the Fox Hills sandstones and overlying fresh-water *Ceratops* beds. The Fort Pierre shales are not suddenly replaced by the Fox Hills sandstones, but the transition is a gradual one, and it is impossible to say just where the one ends and the other begins. The same is true of the beds overlying the Fox Hills. The thin seam of hard sandstone, separating the fossil-bearing Fox Hills sandstones below from the very similar nonfossiliferous sandstone above, is here regarded as the dividing line between the Fox Hills and the *Ceratops* beds. But this decision, it must be admitted, is quite arbitrary, and the evidence in its favor is negative rather than positive. The only reason for placing the overlying 400 feet of nonfossiliferous sandstones in the fresh-water series is the absence of fossils in them.

In discussing the age of the "*Ceratops* beds" Hatcher said:

> Owing to the fact that very few vertebrates had previously been described from the typical Laramie, as first defined by Mr. Clarence King, and the consequent lack of vertebrate forms known to have come from the Laramie for comparison with those found in the *Ceratops* beds, it must be admitted that the vertebrate fauna of the latter is, in itself, at present not sufficient proof to establish the Laramie age of the *Ceratops* beds.

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[98] Marsh, O. C., Additional characters of the Ceratopsidae, with notice of new Cretaceous dinosaurs: Am. Jour. Sci., 3d ser., vol. 39, p. 418, 1890; The gigantic Ceratopsidae, or horned dinosaurs of North America: Idem, vol. 41, p. 167, 1891.

[99] Hatcher, J. B., The *Ceratops* beds of Converse County, Wyo.: Am. Jour. Sci., 3d ser., vol. 45, pp. 135-144, 1893.

Hatcher concluded, however, that the "*Ceratops* beds" should be referred to the Laramie for the following reasons:

> 1. They conformably overlie the Fox Hills sandstones and contain both a reptilian and a mammal fauna, with decided Mesozoic affinities. * * *
>
> 2. They contain an invertebrate fauna comprising many forms identical with those already described from the typical Laramie, some of which are unknown except in the Laramie.
>
> 3. They immediately and conformably overlie the Fox Hills and show evidence of a continuous deposition through both series.

In 1896 Hatcher[1] published another paper dealing with the Converse County area, in which he criticized in the severest manner Marsh's statement that the "*Ceratops* beds" had been traced some 800 miles along the eastern flank of the Rocky Mountains. Hatcher showed that, with the exception of a single specimen from a doubtful locality, all the material studied by Marsh had been found in the Denver Basin, in Converse County, or in the Judith River area. He said:

> These are very widely separated localities, and no attempt has ever been made to trace the continuity of the strata from one to the other, nor is it at all probable that such an attempt would meet with success.

Hatcher also questioned Marsh's statements that the "*Ceratops* beds" are below the uppermost beds referred to the Laramie and that they rest on marine beds which contain invertebrate fossils characteristic of the Fox Hills deposits. Although his comments were somewhat at variance with his former statement, Hatcher continued as follows:

> At no place in the Converse County region do the true *Ceratops* beds, with the remains of horned dinosaurs, rest upon true marine Fox Hills sediments; nor are the *Ceratops* beds in this region overlain by strata which could be referred without doubt to the Laramie. The writer has, in a paper published in the American Journal of Science of February, 1893, stated that the *Ceratops* beds rest directly upon the Fox Hills series and has provisionally referred the very similar series of sandstones and shales conformably overlying the *Ceratops* beds to the upper Laramie; but it would doubtless be better to restrict the limits of the *Ceratops* beds to those strata in which horned dinosaurs occur, and to consider the underlying 400 feet of barren sandstones as the equivalent of the Judith River beds. Future investigations will doubtless show that the sandstones, shales, and lignites overlying the typical *Ceratops* beds in Converse County should be referred to the Fort Union beds and not to the Laramie, as, according to Knowlton, the limited flora sent him now indicates.

In 1896 T. W. Stanton and I[2] spent several weeks in Converse County and also visited numerous localities in Colorado, Wyoming, and Utah, in a study whose object was stated as follows:

> As many of the supposed typical Laramie localities had been visited and studied by the various investigators some years ago, before the recognition of the Arapahoe, Denver, and Livingston formations, it became a matter of interest and importance to revisit these places and ascertain, if possible, the bearing of the new data on the questions of their distribution, life, etc.

In the discussion of the Converse County area in this paper several sections were given showing especially the Fox Hills and overlying "*Ceratops* beds." No fossils of any kind were detected in the 400 feet of sandstones mentioned by Hatcher as occurring above the highest Fox Hills horizon, but just above these sandstones, in the basal portion of the "*Ceratops* beds," though apparently below any remains of dinosaurs, a few brackish-water invertebrates were detected. Particular attention was devoted to the "*Ceratops* beds," and numerous collections of invertebrates and plants were listed.

Regarding the interpretation of the invertebrate fauna, the following statement was made:

> Of the 18 identified species in the above list just half occur at Black Buttes, Wyo., in or very near the bed that has yielded the saurian *Agathaumas sylvestris* Cope. The large proportion of identical forms and the general resemblance of the entire faunas, especially in the large number and great differentiation of species of *Unio*, makes it reasonably certain that the Converse County and Black Buttes beds are on nearly the same horizon. The evidence of the vertebrate fossils seems to trend in the same direction. It will be shown later that the Black Buttes bed should be regarded as true Laramie, and consequently the series now under consideration is placed in the same category.

The plants, of which 25 forms were listed, were compared with the floras of various localities then supposed to be of Laramie age, and the conclusion was reached that "as nearly as can be made out, the plants confirm the Laramie age of the *Ceratops* beds."

From the beds conformably overlying the highest dinosaur-bearing stratum 18 species of plants were obtained, and of the 10 named species 9 proved to be typical Fort Union forms, and hence these beds were regarded as of Fort Union age.

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[1] Hatcher, J. B., Some localities for Laramie mammals and horned dinosaurs: Am. Naturalist., vol. 30, pp. 112-120, 1896.

[2] Stanton, T. W., and Knowlton, F. H., Stratigraphy and paleontology of the Laramie and related formations in Wyoming: Geol. Soc. America Bull., vol. 8, pp. 127-156, 1907.

For more than a decade after the studies resulting in the last-mentioned paper little or no active geologic work was done in the Converse County area, though the collecting of the remains of huge dinosaurs was continued from time to time by several persons. In the meantime, however, it had become known that the ceratopsian dinosaurs that were so abundant and characteristic in the Converse County region were by no means confined to that area. In 1907 Barnum Brown, of the American Museum of Natural History, published a short paper[3] in which he recorded their abundant presence at many localities in Montana. This discovery was made in 1901 by William T. Hornaday, director of the Bronx Zoological Garden, New York, while hunting in the badlands along Missouri River north of Miles City. Here Dr. Hornaday found a number of large bones, one of which was brought home and proved to be the tip of a horn of the large dinosaur *Triceratops*. From 1902 to 1906 Brown was engaged in exploring and collecting in Montana. The principal locality was in the vicinity of Hell Creek, a small stream entering the Missouri about 155 miles northwest of Miles City, but the same dinosaur-bearing beds were found on Yellowstone River at Castle Butte, near Forsyth, at Glendive, at Ekalaka, and at Hocket post office, from which they were thought (and have since been proved) to be continuous with similar dinosaur-bearing beds on the Little Missouri and near Grand and Moreau rivers in South Dakota.

The dinosaur-bearing beds on Hell Creek, named the "Hell Creek beds" by Brown, are described as resting unconformably on Fox Hills beds of varying thickness, while above and representing an uninterrupted continuation of them is a lignite series referred with question to the Fort Union. Above this series is the unquestioned Fort Union with a characteristic flora. In discussing the correlation and age of the "Hell Creek beds" Brown wrote as follows:

> Lithologically the Hell Creek beds of Montana are similar in almost every respect to the *Ceratops* beds of Converse County, Wyo. Most genera and many species of vertebrates and invertebrates are common to both deposits, while the faunal facies may be considered a unit. * * * They are therefore considered of contemporaneous deposition.

In regard to the age of these beds he said:

> Strictly following King's definition of the Laramie, neither of these deposits can be considered as such; for neither one represents a continuous sedimentation from the marine Fox Hills. They should therefore be grouped with the Livingston, Denver, and Arapahoe beds and may be considered post-Laramie.

Although Brown considered the "Hell Creek beds" as post-Laramie and thus comparable to the Arapahoe and Denver formations in position, it is evident from the title of his paper that he still regarded them as Cretaceous.

The year 1907 was also marked by the publication of the monograph on the Ceratopsia by Hatcher and Lull.[4] This comprehensive treatise was mainly the work of Hatcher and had been nearly completed at the time of his death, July 3, 1904. It was compiled and edited by Lull, who added a chapter on the phylogeny, taxonomy, distribution, habits, and environment of the Ceratopsia. From this it appears that the localities then known for the so-called Laramie Ceratopsia were Black Buttes and Converse County, Wyo., and Hell Creek, Mont. The Denver localities were considered under a separate heading, and the statement was made that these beds (Arapahoe and Denver) had been "considered to be of post-Laramie age." It was of course held that all the localities which had afforded the "Laramie Ceratopsia" belonged to the Cretaceous.

In 1905 the United States Geological Survey began an investigation that had for its object the classification of the coal lands in the public-land States of the West, and this work has been continued until the present time. The plan has been to send a party, usually a small one, to survey a definite area for the purpose of ascertaining its coal resources and incidentally of procuring such data as time and opportunity offered on the general geology of the area. In this manner a large and important body of facts has been accumulated regarding the geology of regions or localities that might otherwise have remained obscure or imperfectly known for an indefinite period.

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[3] Brown, Barnum, The Hell Creek beds of the Upper Cretaceous of Montana: Am. Mus. Nat. Hist. Bull., vol. 23, p. 823, 1907.

[4] Hatcher, J. B., and Lull, R. S., The Ceratopsia: U. S. Geol. Survey Mon. 49, 1907.

One of the first of these so-called coal reports was made by A. C. Veatch[5] for a large area in southwestern Wyoming, though the coal report was expanded into a complete consideration of the geology and resources of the region covered. (See p. 67.) In 1906 this work was systematized and prosecuted in all the Rocky Mountain States, though the results were not published until 1907.

In the present connection the report by A. G. Leonard[6] on the coal fields of parts of Dawson, Rosebud, and Custer counties, Mont., is of interest. This was really hardly more than a reconnaissance report on a large area lying mainly between Missouri and Yellowstone rivers and extending from Hell Creek eastward to the State line. Four geologic formations were recognized in this field—Pierre, Fox Hills, "dinosaur-bearing beds" not otherwise named, and Fort Union. In some places, as at Glendive, the Fox Hills was supposed to be absent and the overlying dinosaur-bearing beds rested directly on the Pierre. The dinosaur-bearing beds were described by Leonard as follows:

> Heretofore all the beds above the marine Pierre shale have been regarded as belonging to a single formation which carries the lignite and subbituminous coal beds of this field. These rocks have been called at various times "Laramie" and "Fort Union," on the supposition that they compose but a single formation. The work of the last year, however, has shown that at Glendive the rocks above the Pierre shale apparently comprise two formations. * * * The beds are strikingly similar to the dinosaur-bearing beds [="Hell Creek beds" of Brown] on Hell Creek, and presumably they are identical.

The Fort Union was everywhere conformably above the "dinosaur-bearing beds" and was described as "readily distinguished by the light-gray and buff color of its beds."

The economic coal investigations, which have a more or less direct bearing on the present problem, were continued in 1907, and the results were published in 1909.[7] A. G. Leonard and Carl D. Smith reported on the Sentinel Butte lignite field, in North Dakota and Montana, where they found only the Fort Union formation. Arthur J. Collier and Carl D. Smith reported on the Miles City coal field, in Montana, where also only the Fort Union was recognized, though the lower 500 feet of beds [the equivalent of the "dinosaur-bearing beds" of the Glendive section] was described as showing a marked lithologic difference. In the main only the Fort Union was described by L. H. Woolsey in his account of the Bull Mountain coal field, in Montana, though he mentioned briefly certain beds on Dean Creek and an olive-green shale which he regarded as being beneath the Fort Union. In the report on coal near the Crazy Mountains, Mont., R. W. Stone recognized the marine Cretaceous section as defined by Stanton and Hatcher for the Judith River area (see p. 77), and above this, in ascending order, the Laramie, Livingston, and Fort Union formations. In his report on the Red Lodge coal field, Mont., E. G. Woodruff referred the whole visible section of 8,000 feet to the Fort Union, as did J. A. Taff the coal-bearing section in the Sheridan coal field, Wyo. On the southwest side of the Big Horn Basin of Wyoming Woodruff identified as Laramie (?) a series of sandstones and shales overlying the Montana group. This series was said to contain invertebrates belonging to a fauna characteristic of the "*Ceratops* beds." Woodruff said:

> As the stratigraphic position of these beds ["*Ceratops* beds"] is not definitely determined, the name Laramie is applied because the Laramie formation occupies a position in the geologic column between the Montana and Fort Union. * * * The name, however, should not be considered as indicative of a positive correlation with beds of Laramie age to the south.

The Laramie was also tentatively recognized by C. W. Washburne on the northeast side of the Big Horn Basin, though the evidence aside from position was not very clearly stated.

Up to 1909 there had been no formal, published protest against the reference of the "*Ceratops* beds" to the Cretaceous, although several writers had indicated that in certain areas the stratigraphic relations of the dinosaur-bearing beds were such that they were at variance with the original definition of the Laramie. In this year I published a paper[8] under the title "The stratigraphic relations and paleontology of the 'Hell Creek beds,' '*Ceratops* beds,' and equivalents, and their reference to the Fort Union formation," in which the following was given as the thesis:

> The present paper deals with the extensive series of fresh-water deposits of the Northwest, comprising what is

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[5] Geography and geology of a portion of southwestern Wyoming, with special reference to coal and oil: U. S. Geol. Survey Prof. Paper 56, 1907.

[6] U. S. Geol. Survey Bull. 316, p. 194, 1907.

[7] U. S. Geol. Survey Bull. 341, 1909.

[8] Knowlton, F. H., Washington Acad. Sci. Proc., vol. 2, pp. 179–238. 1909.

here considered as the Fort Union formation. It is shown that the Fort Union embraces more than has been commonly assigned to it. Conformably below the beds by some geologists considered as the true Fort Union occur dark-colored sandstones, clays, and shales, which have often been incorrectly referred to the Laramie or its equivalent but which are stratigraphically and paleontologically distinct from the Laramie, and the contention is here made that these beds, which include the "Hell Creek beds" and so-called "somber beds" of Montana, the "*Ceratops* beds" or "Lance Creek beds" of Wyoming, and their stratigraphic and paleontologic equivalents elsewhere, are to be regarded as constituting the lower member of the Fort Union formation and are Eocene in age.

In this paper a brief historical summary of the Fort Union formation was followed by an account of its areal distribution and lithologic character, in which I held that it may be divided into two members. The areal distribution and paleontologic contents of the lower or dinosaur-bearing member were given as completely as available facts then warranted. The distribution included the following areas in Montana: Hell Creek, Miles City and vicinity, Forsyth, Custer, Bull Mountains, Melville, Red Lodge, Glendive, and from Glendive to Medora, N. Dak. Several areas in North Dakota were discussed, as well as a probable area (since confirmed) in northwestern South Dakota. Thence the formation was traced to Weston County, Wyo., and thence northward to connect with the area at Miles City, Mont. Other areas in Wyoming were Converse County, a great region east of the Big Horn Mountains, and the Big Horn Basin. Thus it was shown that the "*Ceratops* beds," originally supposed to occur only in Converse County, Wyo., really occupy a vast area distributed over four great States.

The essential results claimed in this paper were sufficiently set forth in the "summary and conclusions," as follows:

1. The Fort Union formation is a fresh-water Tertiary formation of wide areal extent, mainly east of the Rocky Mountains, ranging from Wyoming and western South Dakota over western North Dakota, eastern and central Montana, the central Canadian Provinces, and reaching the valley of the Mackenzie River.

2. It is shown that the Fort Union formation may be separated into two members on lithologic grounds. The present paper deals only or largely with the stratigraphy and paleontology of the lower member, which includes the "Hell Creek beds" and so-called "somber beds" of Montana and the "*Ceratops* beds" of Wyoming.

3. The areal distribution of the lower member is traced in Montana, North and South Dakota, and Wyoming, and its probable extension in other areas is indicated. Complete lists of the fossil plants are given by localities for each of the areas.

4. It is shown that the lower member rests, in some cases unconformably, in others in apparent conformity, on the Fox Hills or Pierre, and the conclusion is reached that an erosional interval is indicated during which the Laramie—if ever present—and other Cretaceous and early Tertiary sediments were removed.

5. It is shown that the beds under consideration, being above an unconformity, can no longer be considered as a part of the "conformable Cretaceous series" and hence are not Laramie.

6. It is shown that the two members of the Fort Union, although usually distinct lithologically, can not be separated structurally, sedimentation having been uninterrupted, except locally.

7. The paleontological elements of the lower members are considered at length, beginning with the plants. It is shown that of the 84 known species, 61 are common to the upper member, and only 11 species to the Laramie of Colorado, while 15 species are common to other American Eocene, and 9 species to the Miocene. The Eocene age of the Fort Union is fixed by tying its flora to that of various Old World beds of known Eocene position.

8. The invertebrate evidence is shown to be in substantial accord with that of the plants, there being only 4 of the 49 species common to the Colorado Laramie. All, with a single possible exception, are fresh-water forms.

9. It is shown that the vertebrates afford no positive evidence of Cretaceous age. That the dinosaurs exhibit Cretaceous affinities is not denied, since, being without known descendants, it is possible to compare them only with their progenitors. It has been proved beyond question that they survived the profound orogenic movement and attendant physical break at the top of the Laramie in the Denver Basin of Colorado and lived on in Arapahoe and Denver time, and it is shown that in the areas considered in this paper they passed over a similar erosional interval and are found in association with the Fort Union flora, which is of Eocene age.

10. The mammals of the lower Fort Union show very little relationship with Jurassic or Cretaceous forms but find their closest affinities with those of the Puerco and Torrejon, which are of acknowledged Eocene age.

11. The chelonians are shown to be of little value in their bearing on the age of the lower Fort Union, especially when compared with the Judith River forms, which are evidently in confusion.

12. It is held that the line between Cretaceous and Tertiary should be drawn at the top of the true Laramie.

13. The final conclusion is reached that the beds here considered ("Hell Creek beds," "somber beds," "*Ceratops* beds," "Laramie" of many writers) are stratigraphically, structurally, and paleontologically inseparable from the Fort Union and are Eocene in age.

The above-mentioned paper was followed almost immediately by a paper by T. W. Stanton,[9] entitled "The age and stratigraphic relations of the '*Ceratops* beds' of Wyoming and Montana." The thesis of this paper was stated as follows:

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[9] Washington Acad. Sci. Proc., vol. 2, pp. 239-293, 1909.

> The purpose of the present paper is to show that some of the data already used in the discussion [by Knowlton, Cross, and others] are capable of a different interpretation and to call attention to some additional facts which ought to be fully considered before a final verdict is reached. All are agreed that the strata in question are near the boundary between Cretaceous and Tertiary. My opinion is that the greater weight of evidence places them on the Cretaceous side.

Under the head of "local stratigraphy and paleontology" Stanton reviewed a number of the areas in Wyoming and Montana considered in my paper and set forth his own field observations and interpretation of the stratigraphic and paleontologic conditions. In summarizing these data Stanton said:

> It has been shown that, within the large area considered, the "*Ceratops* beds" with the *Triceratops* fauna are always pretty closely associated with the uppermost Cretaceous strata or are separated from them by transitional brackish-water beds. They are always overlain by a thick series of rocks containing a Fort Union flora in which no dinosaurian remains have been found, and in the Fish Creek, Mont., region this overlying series also contains primitive mammals related to those of the Puerco and Torrejon faunas. Throughout a large part of the area no evidence of an unconformity beneath the "*Ceratops* beds" has been found, while higher in the section unconformities have been demonstrated or suggested at a number of places. Unconformities have been reported below the "*Ceratops* beds" on Hell Creek, Mont., on the Little Missouri, in North Dakota, and in Weston County, Wyo., but in none of these cases has any proof been furnished that the erosion interval is important.

The conclusions reached in this paper are given as follows:

> In the interior region of North America the formations between the uppermost marine Cretaceous and the Wasatch together constitute a real transition from the Cretaceous to the Teritary.
>
> Notwithstanding the fact that there are several local unconformities at various horizons and perhaps some of more general distribution, there is no conclusive evidence that any one of these represents a very long period of erosion not represented by sediments elsewhere in the region.
>
> The Fort Union formation, properly restricted, is of early Eocene age, the determination resting chiefly on its stratigraphic position and its primitive mammalian fauna, which is related to the earliest Eocene fauna of Europe. The very modern character of the flora tends to confirm this correlation.
>
> The "*Ceratops* beds" are of Cretaceous age as decided by stratigraphic relations, by the pronounced Mesozoic character of the vertebrate fauna with absence of all Tertiary types, and by the close relations of the invertebrate fauna with the Cretaceous. The relation of the flora with Eocene floras is believed to be less important than this faunal and stratigraphic evidence. Taken in their whole areal extent, they probably include equivalents of the Laramie, Arapahoe, and Denver formations of the Denver Basin.

Hay[10] also published a paper in 1909 on the position and age of the "*Ceratops* beds," in which, after comparing the fauna of these beds with those of the Judith River, Puerco, Torrejon, and several European formations, he concluded as follows:

> 1. The answer that the writer would give to the question at the head of this paper is that the Lance Creek beds belong to the Upper Cretaceous.
>
> 2. In the Upper Cretaceous ought to be included also the Puerco and not improbably also the Torrejon and Fort Union.
>
> 3. In case of a conflict between the evidence furnished by the flora and the fauna of the Lance Creek beds and those of the Fort Union respectively, the evidence obtained from the fauna is to be preferred, as being part of a more complete and better understood history. Present knowledge regarding plants seems to indicate that they were precocious, having reached something like their present stage of development long before mammals attained anything like their present stages of differentiation. There are also indications that the floras of the western world were, during the Cretaceous, considerably in advance of those of Europe.
>
> 4. Even if it were concluded that the Fort Union belongs to the Tertiary, and that the fauna and flora of the Lance Creek epoch are more closely related to those of the Fort Union than they are to those of the Judith River, it does not follow that the Lance Creek epoch must be included in the Tertiary. A quarter before midnight on Monday is much nearer to Tuesday than it is to the previous 6 o'clock; nevertheless, it is not yet Tuesday.

The work of the United States Geological Survey in classifying the coal lands was continued in 1908, though the results of this year's investigations were not published until 1910.[11] It is noteworthy that in the areas falling within the scope of the present review the Fort Union has come to be placed unqualifiedly in the Tertiary.

In the volume cited R. W. Richards has a paper under the title "The central part of the Bull Mountain coal field, Mont.," in which the stratigraphic relations are set forth in the following table:

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[10] Hay, O. P., Where do the Lance Creek ("*Ceratops*") beds belong—in the Cretaceous or in the Tertiary?: Indiana Acad. Sci. Proc., vol. 25, 1909.

[11] U. S. Geol. Survey Bull. 381, 1910.

Stratigraphy of the central part of the Bull Mountain coal field, Mont.

System.	Formation.	Thickness (feet).	Description.
Tertiary...	Fort Union.	1,650	Yellowish sandstones and shales interstratified with lignite beds.
(?)........	....	200–300	Somber-colored shale and coarse yellow sandstones with beds of carbonaceous sandstone and shale.
Cretaceous.	Laramie (?)	1,480	Alternating gray sandstones and clay shales, with thin coal beds.
	Bearpaw...	....	Gray to brown shales and clay.

The Laramie (?) was regarded as the equivalent of the "somber beds" of the Miles City field.

The Buffalo coal field, Wyo., was described in this bulletin by H. S. Gale and C. H. Wegemann. In this area the dinosaur-bearing beds were referred to the so-called Piney formation, which was said to be pre-Tertiary or Cretaceous [both terms are used in the report], though some doubt was expressed as to whether this designation would prove to be correct.

In 1910 T. W. Stanton[12] published a short paper dealing with this subject and recording new field data from areas in the Dakotas and eastern Wyoming. The term Lance formation, which has now come into such general usage, was here published for the first time and was specifically stated to be a substitute for the old terms "*Ceratops* beds," "Lance Creek beds," and equivalents. Of the three areas discussed in this paper the one first considered was the Standing Rock and Cheyenne River Indian Reservation, or the region between Grand and Cannonball rivers in North and South Dakota. In this area attention was directed principally to the Fox Hills sandstone and its contrast with overlying beds, and a number of sections were given, together with lists of the invertebrates found. Stanton said:

> At the top of the Fox Hills sandstone with its purely marine fauna there is a rather thin but widely distributed brackish-water bed, which contains *Ostrea*, *Anomia*, *Corbicula*, *Melania*, etc., in great abundance. The zone in which this fauna occurs varies in thickness from 3 or 4 feet up to 40 feet and is lithologically very similar to the underlying marine beds, but its base is irregular at many places and shows channeling and other evidences of erosion. It was therefore regarded by the field geologists as the basal member of the overlying Lance formation resting unconformably on the Fox Hills. In the study of this brackish-water bed evidence was found at several localities, distributed over a considerable area, that there is a distinct transition without a break of any importance between the marine Fox Hills sandstone and the brackish-water deposit. The paleontologic evidence consists of distinctive Fox Hills species belonging to such marine genera as *Scaphites*, *Lunatia*, and *Tancredia*, found directly associated in the same bed with the brackish-water forms and occurring with them in such a way that they must have lived together or near each other and been embedded at the same time.

The second area included the valley of the Little Missouri from Marmarth to Yule, N. Dak. The point emphasized with reference to this area was the finding of an oyster bed some 500 feet above the base of the Lance formation and above all the dinosaurs that have been found in the region.

The Lance Creek area in Converse County, Wyo., which had been reexamined in company with M. R. Campbell and R. W. Stone, was the third area considered. Of this area Stanton said:

> Our principal contribution to the knowledge of the stratigraphy of the area was the discovery that the marine Fox Hills deposits extend about 400 feet higher than had previously been determined, and that nonmarine coal-forming conditions were temporarily inaugurated here before the close of Fox Hills time.

In conclusion Stanton wrote:

> The three areas discussed in this paper, taken together, tell a story of gradually changing conditions near the end of the Cretaceous, when the uplift of the Rocky Mountain region was draining the interior sea. The uplift was not uniform nor continuous, and the emergence above sea level could not have been simultaneous for all localities throughout the region. * * * The bearing which the facts here presented have on the Laramie problem is self-evident. If it is true that there is a transition with practically continuous sedimentation from the Fox Hills sandstone into the Lance formation in the region discussed, then the Lance formation includes or forms part of the Laramie.

The first published official statement showing that the discussion concerning the age of the Lance formation was having its effect is to be noted in a short report on the eastern part of the Bull Mountain coal field, Mont., by C. T. Lupton.[13] Here for the first time the Lance formation was classed as "Cretaceous or Tertiary."

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[12] Fox Hills sandstone and Lance formation ("*Ceratops* beds") in South Dakota, North Dakota, and eastern Wyoming: Am. Jour. Sci., 4th ser., vol. 30, pp. 172-188, 1910.

[13] U. S. Geol. Survey Bull. 431, p. 163, 1911.

In May, 1911, I published a short paper[14] entitled "Further data on the stratigraphic position of the Lance formation ('*Ceratops* beds')," which gave the results of the work of the two field seasons that had intervened since the publication of my first paper on this subject. What was then thought to be the most important result recorded was the finding in Carbon County, Wyo., of the remains of *Triceratops* in the so-called "Upper Laramie" of Veatch, above the supposed profound unconformity as described and mapped by him. After describing this occurrence I made the following statement:

> Since, with the exception of their occurrence in the post-Laramie deposits of the Denver Basin, the remains of *Triceratops* have never been found outside the Lance formation, the finding of *Triceratops* at this point is of far-reaching importance. It shows that not only are the beds containing them above more than 6,000 feet of "Laramie" rocks (the basal portion of which is almost certainly of Fox Hills age), but also that they are separated from the "Laramie" ["Lower Laramie"] by an unconformity, which, according to Veatch, is profound and has involved the removal of perhaps as much as 20,000 feet of sediments. This would seem effectively to dispose of the contention that the Lance formation ["*Ceratops* beds"] is the equivalent of the Laramie.

Another part of this paper was an important contribution of several pages by W. R. Calvert, on the stratigraphic relations in the old Standing Rock and Cheyenne Indian Reservation, in South and North Dakota, as observed by him and by the parties under his charge. In this contribution particular attention was devoted to the Fox Hills and the overlying Lance formation. Calvert said: "As a result of field study by Pishel, Barnett, and the writer, it seems certain that the line between the Fox Hills sandstone and the Lance formation is marked by an unconformity." Calvert pointed out that the Fox Hills has a maximum thickness of 200 feet in this region, but it was found to vary greatly, and in some places it was entirely absent, the Lance formation resting on the Pierre. Angular as well as erosional discordances between the two were noted.

Calvert was of the opinion that the reported occurrence of Fox Hills invertebrates in the lower part of the Lance

> may be looked at from two divergent points of view. Because Fox Hills fossils occur in the lignitic shales at the base of the "somber beds" and mingled with the brackish-water types of the Lance formation is not necessarily proof positive that the various faunas lived at the same time, for if the deposition of the Fox Hills was followed by a definite erosion interval, what is more probable than that in the deposition of succeeding strata fossil shells would be eroded from the marine beds and carried into the channels, there to mingle with the then living brackish-water fauna of the Lance formation?

The conclusions reached in this paper were in part as follows:

> It has now been demonstrated that the Lance formation is everywhere followed conformably by the acknowledged Fort Union—that is to say, sedimentation from one to the other was continuous and uninterrupted.

The unconformable relations between the Lance formation and underlying formations having been demonstrated at so many points, it could only be concluded that this

> unconformity is undoubtedly one of importance, and this would seem to dispose of the contention that the Lance, Arapahoe, and Denver formations may be mere "phases of Laramie." * * * This point becomes more clearly than ever the logical point at which to draw the line between Cretaceous and Tertiary.

Later in 1911 I published a short note[15] under the caption "Where are the Laramie dinosaurs?" In this note the facts regarding the relations between the Laramie and Lance formations, as recorded in previous papers, were briefly set forth, and I concluded with the following paragraph:

> The vertebrate paleontologists continue to refer to the "*Ceratops* beds" as the "Laramie," the "Laramie Cretaceous," etc., as though nothing had been ascertained regarding their position since they were named 25 years ago. If there *is* valid evidence to show that the Lance formation ("*Ceratops* beds") is the equivalent to the Laramie in whole or in any part, it would be welcome. If there *is* a known locality where dinosaurs (Ceratopsidae) occur in the true Laramie, information concerning it should not longer be withheld.

The report on the work of the United States Geological Survey on mineral fuels for the year 1910, published in 1912,[16] contains many short papers and preliminary reports relating to Rocky Mountain areas, here under consideration. In these papers, by Pishel,[17] Calvert,[18]

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[14] Jour. Geology, vol. 19, pp. 358-376, 1911.

[15] Science, new ser., vol. 34, p. 320, 1911.

[16] U. S. Geol. Survey Bull. 471, 1912.

[17] Pishel, M. A., Lignite in the Fort Berthold Indian Reservation, N. Dak.: Idem, p. 170.

[18] Calvert, W. R., Geology of certain lignite fields in eastern Montana: Idem, p. 187.

Bowen,[19] Herald,[20] Hance,[21] Stebinger,[22] Beekly,[23] Wegemann,[24] Winchester,[25] and others, the Lance formation was uniformly classed as "Cretaceous or Tertiary." It is not necessary to refer to these papers in detail, except to that of Calvert, in which he recorded certain facts of importance relating to a large area in eastern Montana. He divided the Lance formation of this area into two parts—a lower sandstone member, immediately overlying the Pierre and named the Colgate sandstone member, and an upper or undivided portion. As regards the line between the Lance and the overlying Fort Union he said:

> In the area mapped the upper limit of the Lance formation can not be based on lithologic grounds but must instead be dependent upon the occurrence of fossil Ceratopsia bones. In the area treated in this report the highest horizon at which these bones were found is just above the lower persistent lignite bed, but there is certainly nothing in the character of the overlying strata to suggest that similar bones do not occur therein up through a stratigraphic distance of perhaps 500 feet. * * * As a result of these conditions no attempt is made on the index map or on the maps of the various areas treated in this report to differentiate the Lance formation from the overlying strata described in connection with the Fort Union formation. * * * In other words, the area bounded on one side by the contact between the Pierre shale and the Colgate sandstone member and on the other side by the outcrop of the lowest persistent lignite bed represents the distribution of the Lance formation as mapped in this field. In this connection, however, it can not be emphasized too strongly that the upper limit adopted is merely suggestive, as the finding of *Triceratops* bones higher in the section will necessitate an upward extension of the formation.

At the meeting of the Paleontological Society in Princeton, N. J., December 31, 1913, and January 1, 1914, there was held a symposium on the "Close of the Cretaceous and opening of Eocene time in North America," which was briefly introduced by Henry Fairfield Osborn, and in which Messrs. Knowlton, Stanton, Brown, Matthew, and Sinclair participated.

In the first paper [26] the following was given as the thesis:

> It is proposed to show that the dinosaur-bearing beds known as "*Ceratops* beds," "Lance Creek beds," Lance formation, "Hell Creek beds," "somber beds," "lower Fort Union," Laramie of many writers, "Upper Laramie," Arapahoe, Denver, Dawson, and their equivalents are above a major unconformity and are Tertiary rather than Cretaceous in age.

The evidence was presented under the headings stratigraphic, paleobotanic, diastrophic, European time scale, vertebrates, and invertebrates. In the discussion of stratigraphic evidence it was held "that the dinosaur-bearing beds above mentioned are separated from underlying beds by a major unconformity which makes the logical line of separation between Cretaceous and Tertiary." The evidence bearing on the occurrence of this unconformity was traced throughout North and South Dakota, Montana, Wyoming, Colorado, and New Mexico and was demonstrated in a number of ways, including angular and erosional discordance, as well as faunal and floral differences.

The paleobotanic evidence was naturally presented in extenso. It was shown that the floras in the beds immediately below and above the line of the unconformity comprise about 350 species in the lower beds (Vermejo, Laramie, Montana, etc.) and over 700 species in the upper beds (Raton, Dawson, Arapahoe, Denver, Lance, etc.) but that they have only 21 or 22 species in common, showing "that more than 90 per cent of the Cretaceous flora was wiped out by the disturbance attending this diastrophic movement."

In the Raton Mesa region of Colorado and New Mexico the beds immediately above the unconformity have been named the Raton formation and contain a flora of 148 species, only 4 of which are common to the underlying Vermejo, which is below the line of the unconformity. The Raton flora was correlated with those of the Wilcox group of the Gulf coast and of the Dawson, Arapahoe, and Denver formations to the north. The correlation was carried from the Denver Basin of Colorado through North Park and into Carbon County, Wyo., where the "Upper Laramie" of Veatch was held to be of the same age as the Lance formation of Converse County, Wyo., and thence throughout Montana and the Dakotas. "The Lance flora embraces about 100 named and described species. Of these 100 species, over 75 are typical Fort Union species that have never been found in older beds and most of them only in the Fort Union." The Fort Union was said to be of acknowledged Eocene age.

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[19] Bowen, C. F., The Baker lignite field, Custer County, Mont.: Idem, p. 202.

[20] Herald, F. A., The Terry lignite field, Custer County, Mont.: Idem, p. 227.

[21] Hance, J. H., The Glendive lignite field, Dawson County, Mont.: Idem, p. 271.

[22] Stebinger, Eugene, The Sidney lignite field, Dawson County, Mont.: Idem, p. 284.

[23] Beekly, A. L., The Culbertson lignite field, Valley County, Mont.: Idem, p. 319.

[24] Wegemann, C. H., The Sussex coal field, Johnson, Natrona, and Converse counties, Wyo.: Idem, p. 441.

[25] Winchester, D. E., The Lost Spring coal field, Converse County, Wyo.: Idem, p. 472.

[26] Knowlton, F. H., Cretaceous-Tertiary boundary in the Rocky Mountain region: Geol. Soc. America Bull., vol. 25, pp. 325-340, 1914.

In discussing the European time scale it was shown that

> (1) The Cretaceous and Tertiary systems were originally established on a physical basis, and the exact line of separation between them was determined by the structure; (2) after more than a century, during which the several lines of evidence have been tested, the last authoritative word on the European standard is to the effect that the structure is the determining factor in separating them, and that even dinosaurs that have been appealed to so often as proof of Cretaceous age did not end with the Cretaceous.

The vertebrate and invertebrate evidence was briefly considered. In conclusion, the thesis given at the beginning of the paper was repeated and considered as follows:

> Evidence, believed to be competent, has been presented in support of this view from the side of stratigraphy, diastrophism, and paleobotany, and what is thought to be the weakness and insufficiency of the vertebrate and invertebrate evidence has been pointed out. The vertebrate paleontologist would place the Cretaceous-Tertiary line at the highest horizon at which dinosaurs have been found, notwithstanding the fact that this is a variable boundary, unattended by structural or diastrophic action. The invertebrate paleontologist would place this line at the highest point where marine invertebrates of Cannonball type occur. The paleobotanist would place the line at the lowest horizon at which Tertiary plants have been found, which corresponds with the structure. The paleontologists are not in accord. What, then, is to be the court of final appeal? There is but one answer: Structure resulting from diastrophism. The evidence from these sources supports the thesis.

The second paper of the symposium, by T. W. Stanton,[27] began with a discussion of the typical Cretaceous and Eocene of western Europe, in which it was held that the Anglo-Parisian basin "can perhaps with justice be considered the typical area of both Cretaceous and Eocene." It was shown that here there is a well-marked structural break, as well as a strong faunal break, and it is of course easy to distinguish between them, but that in other areas (Denmark, Belgium, center of Paris Basin, etc.) there are deposits,

> in part marine and in part continental, which seem to belong between the highest Cretaceous and the lowest Eocene represented in England. These intermediate deposits have been called Danian, Montian, and other more local names and have been assigned by some geologists to the Cretaceous, by others to the Tertiary, and by still others part to the Cretaceous and part to the Tertiary. * * *
>
> All will agree, I think, that when two contiguous systems as originally defined are separated by an unconformity, if there is other evidence of a break in sedimentation, it is probable that intermediate deposits will be found in some part of the world, and that when found, if they are subordinate in character, they should be assigned in each case to the system to which they are most closely related.

In discussing the contact between marine Cretaceous and marine Eocene in North America, Stanton pointed out that

> In America, as in England, wherever marine Cretaceous is directly overlain by marine Eocene, there is no difficulty in recognizing the boundary between them, and there is no controversy concerning the boundary. * * * In the Interior Province, including the Great Plains and Rocky Mountain region, conditions were different. The Upper Cretaceous sea during the Colorado epoch covered a large part, if not the whole, of the province, and by the end of the Cretaceous it had entirely retreated from the area; but the Eocene sea did not return into this province at all. Instead of marine deposits great continental deposits were formed, beginning in the Cretaceous and continuing with many interruptions and with increasing restriction of areas throughout Tertiary time.

As regards the evidence of land areas in the Rocky Mountain region during the Cretaceous, Stanton wrote as follows:

> The idea has sometimes been expressed that this was a period of quiet and universal submergence for the province, with no land masses within it until the end of the period, when the whole area was lifted above sea level by a single movement. There are many facts opposed to this view—so many that they form convincing evidence that at several times during the period there were differential movements which brought previously submerged local areas above sea level. The greatest submergence of the sea, and presumably the deepest submergence, seems to have been near or after the middle of the Colorado epoch; but even at that time it is probable that there were large islands. Local variations in thickness and character of sediments bespeak the nearness of land at some localities.

As examples in support of this contention were given the Datil Mountain area in western New Mexico, where a land flora was developed in the Colorado; the Mesaverde formation of Colorado, Wyoming, Utah, etc., which shows extensive coal deposits; various coal fields of the Colorado epoch in Utah and Wyoming; coal and fresh-water deposits in the Eagle and Judith River formations; and finally, the volcanic activity which furnished material for the Livingston formation in the area about the Crazy Mountains in Montana.

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[27] Boundary between Cretaceous and Tertiary in North America, as indicated by stratigraphy and invertebrate faunas: Geol. Soc. America Bull., vol. 25, pp. 341-354, 1914.

Stanton also devoted several pages to the consideration of the Lance formation, including its distribution and general character, its development in North and South Dakota, and particularly the marine member and its fauna. Regarding this fauna he said:

> In my opinion, the invertebrates from the marine member of the Lance belong to a Cretaceous fauna. This is indicated both by their close relationship with the Fox Hills fauna and by the known paleogeographic facts of the late Cretaceous and the Eocene. The fauna contains a number of species identical with Fox Hills forms, others that are closely related, a few that were ascribed to the Fox Hills but apparently were actually collected by the early explorers from beds now assigned to the marine member of the Lance, and a considerable number of new species, which, so far as known, do not occur outside of the marine member. * * * The fauna lacks a number of common Fox Hills species and contains a considerable proportion of new forms, so that it may be called a modified Fox Hills fauna.

The conclusions reached are stated as follows:

> In my opinion, therefore, the conclusion is justified that the Cretaceous period did not end in the interior province until the sea had completely retreated from the province, and that the Lance formation should be assigned to the Cretaceous.
>
> The final retreat of the Cretaceous sea from the interior province was doubtless associated more or less closely with local orogenic movements which caused active erosion to begin or to increase in various areas; but in other areas within the province the products of this erosion were laid down as terrestrial deposits, which taken together practically bridge the gap between Cretaceous and Tertiary. The boundary between the two systems in such areas is not marked by an important break caused by general diastrophism, because the breaks and discordance and erosion intervals in an area of continental deposition are not dependent on the same conditions that cause the major breaks in marine sediments. Even if it be true that there was a world-wide movement at the close of the Cretaceous which caused a break between marine Cretaceous and marine Eocene in all the areas where such sediments are now accessible, such a movement would not necessarily affect the accumulation of continental deposits of detrital material in an area already above sea level, and in this case apparently it did not affect it. On the other hand, terrestrial deposits are characteristically and necessarily irregular, and the importance of breaks and unconformities in them must therefore be tested with great care, using all kinds of available evidence.
>
> The Lance formation is believed to be Cretaceous on account of its intimate stratigraphic relation with the underlying marine Cretaceous, on account of the close relationship of its vertebrate and nonmarine invertebrate faunas with Cretaceous faunas, and on account of the occurrence in one area of a marine Cretaceous fauna within the formation. This marine Cretaceous invertebrate fauna is held to establish the Cretaceous age of the plants which occur in the beds beneath it, in spite of the fact that these plants are said to belong to Eocene species. In other areas where the Lance formation does not include a marine member but has a thicker development of strata, with a large vertebrate fauna of Mesozoic types, it is a fair inference that the whole formation, with its contained flora, is also of Cretaceous age. If, then, the Lance flora is in fact a Cretaceous flora, notwithstanding its close relationship with Eocene floras, it is obvious that the correlation of other formations with known Eocene formations on the evidence of fossil plants alone is open to serious question. In the case of the Denver and Arapahoe formations such a correlation is directly opposed by the evidence of the vertebrate fauna, which allies them closely with the Lance formation.

In the contribution of Barnum Brown[28] to this symposium he stated that he had been "continuously engaged since June, 1900, in the exploration of the geology, flora, and fauna of three great formations which in their animal and plant life bridge over the passage from Cretaceous to Eocene time, as determined by the comparison with the life of the same epochs in Europe." These formations are "Hell Creek formation of northern Montana; series embracing in descending order Paskapoo, Edmonton, Fort Pierre (upper), Belly River (intercalation), Fort Pierre (lower) of Red Deer River, Alberta; Ojo Alamo formation of northern New Mexico; Lance Creek formation of Converse County, Wyo."

In a former paper Brown had described his "Hell Creek beds" as resting unconformably on the underlying Fox Hills, but this statement he now desired to modify. He described a number of localities in which "these marine beds [Fox Hills] have been eroded in places, sometimes to a depth of 10 feet, before the succeeding massive sandstone of the fresh-water 'Lance' was deposited." This break, he concluded, "is evidently of local erosional character," as "the strata are, however, in all cases parallel to the bedding planes of the succeeding sandstones."

The Paskapoo and Edmonton formations as exposed along Red Deer River, Alberta, were described at some length. The conclusion was reached that the Paskapoo has a mammal fauna in which "the multituberculates and trituberculates are unmistakably those of the Lance, but the placental mammals have not been found in the Lance and appear to belong to the Paleocene groups of mammals," while the invertebrates "are suggestive of Fort Union rather than earlier forms." The Edmonton formation, although containing a flora, at least in the upper part, that is undoubtedly indicative of Fort Union age, was concluded to be Cretaceous and older than Lance on account of the presence of a plesiosaur (*Leurospondylus*), a marine reptile "clearly of Mesozoic age," above the plants. Brown concluded as follows:

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[28] Cretaceous Eocene correlation in New Mexico, Wyoming, Montana, Alberta: Geol. Soc. America Bull., vol. 25, pp. 335-380, 1914.

> From the vertebrate and invertebrate remains it seems very clear that these rocks are not of Fort Union age, but as shown by the plants the climatic conditions of Fort Union time were long foreshadowed toward the close of the Cretaceous.

The dinosaur-bearing beds beneath the Puerco formation of northern New Mexico were briefly described under the name Ojo Alamo beds.

The final conclusion of the paper was as follows:

> There is no doubt that the Hell Creek beds were synchronous with the Lance, and little doubt that the Belly River and Ojo Alamo beds should be correlated with the Judith River. The Edmonton is intermediate in age between the Judith River and the Lance.

W. D. Matthew[29] stated that the term "Paleocene" as he used it "denotes what we have been calling basal Eocene, comprising the Fort Union, Puerco and Torrejon, and other equivalent formations older than Wasatch or typical lower Eocene." Matthew gave lists of the vertebrate faunas of the Puerco, Torrejon, Paskapoo, and Fort Union and made comparisons between them and those of the Lance and Belly River and with the Wasatch. In an interpretation of the faunas he stated: "The evidence of fossil vertebrates in correlation is very valuable, provided it is interpreted correctly." The difference between two faunas may be due, he said, to "lapse of time; difference of local environment; migration movements representing a change in environment somewhere else, not necessarily in the region concerned." With these precautions in mind Matthew presented the table reproduced in figure 1.

The correlation of the faunas here involved with the European succession is of special interest. It was shown that the Thanetian (Cernaysian) has furnished a "small fauna of mammals and reptiles, comparable in facies to our Torrejon and apparently of equal age." The Sparnacian and Ypresian, which include the London clay, the Argiles plastique of the Paris Basin, and equivalents in Belgium and elsewhere, are equivalent to our Wasatch. According to Matthew, the Puerco, arbitrarily correlated by Osborn with the Montian, "has no certain equivalent in Europe," and he stated that the "Lance is equally difficult to correlate," as "there are no European formations of corresponding facies in the late Cretaceous."

As regards faunal migrations and diastrophism the following statements were made:

> As I read the evidence from the vertebrates it is to this effect:
>
> 1. From the Belly River to the Lance there is a considerable lapse in time, but they represent the same faunal facies and they indicate that there was no great migration movement intervening, and hence no great upheaval, either continental or universal. There was undoubtedly a considerable local uplift along the Rocky Mountain ridges and extensive recession of the sea from the plains to eastward of them.
>
> 2. Between the Lance and the Paleocene there is a somewhat smaller lapse in time but a very marked change in fauna; but they do not represent the same facies, and while a great migration movement is probably indicated by the extinction of the dinosaur phyla and incoming of certain groups of placental mammals (Creodonta, Condylarthra, etc.), its extent remains a little uncertain.
>
> 3. Between the Paleocene and Eocene a great migration movement intervenes, the progressive orders of placental mammals, of turtles, and perhaps other groups appearing simultaneously in Europe and North America. The lapse of time between the uppermost Paleocene and lowest Eocene is slight.
>
> If, therefore, we are to use diastrophic criteria as the basis of our geologic classification, the dividing line between Cretaceous and Tertiary should be drawn either between the Lance and the Paleocene or between the Paleocene and Eocene. It should not be drawn between Belly River and Lance.

The following is Matthew's conclusion:

> The question to my mind shapes itself thus: Does the evidence conclusively support the present classification; and, if not, is it sufficiently conclusive to warrant our changing it? I have indicated what I regard as the weight and trend of the vertebrate evidence. Without entering into any detailed criticism of the stratigraphic and paleobotanic evidence, a task for which others are far more competent, I may say that to me it appears to be inconclusive because it does not allow for the characteristics of epicon-

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[29] Evidence of the Paleocene vertebrate fauna on the Cretaceous-Tertiary problem: Geol. Soc. America Bull., vol. 25, pp. 381-402, 1914.

tinental formations nor for the varying facies of faunas and floras; that the asserted magnitude of the break between Laramie and Lance rests not on evidence but on a definition of the Laramie; and that no really adequate evidence has been adduced of its relations to the Cretaceous-Tertiary break in Europe. The paleobotanic argument for placing the Lance in the Tertiary is the resemblance of its flora to that of the Paleocene and its great difference from that of the true Laramie. But there is no evidence that the Lance flora was absent from Europe in the late Cretaceous, and the Laramie clearly represents a different facies from the Lance. Dr. Knowlton has insisted strongly on the entire absence of dinosaurs in the true Laramie, apparently with the idea that it showed it to be much older than the Lance. But as the same phyla of dinosaurs are present in the older Belly River and in the newer Lance, their absence from the Laramie is obviously due to a difference in environmental conditions. The facies of the fauna is different, and much, if not all, of the difference in flora should be ascribed to this cause.

For these and many other reasons the evidence in favor of transferring the Lance and associated formations to the Tertiary appears to me inconclusive and is directly in conflict with the evidence from fossil vertebrates, so far as I am able to understand it.

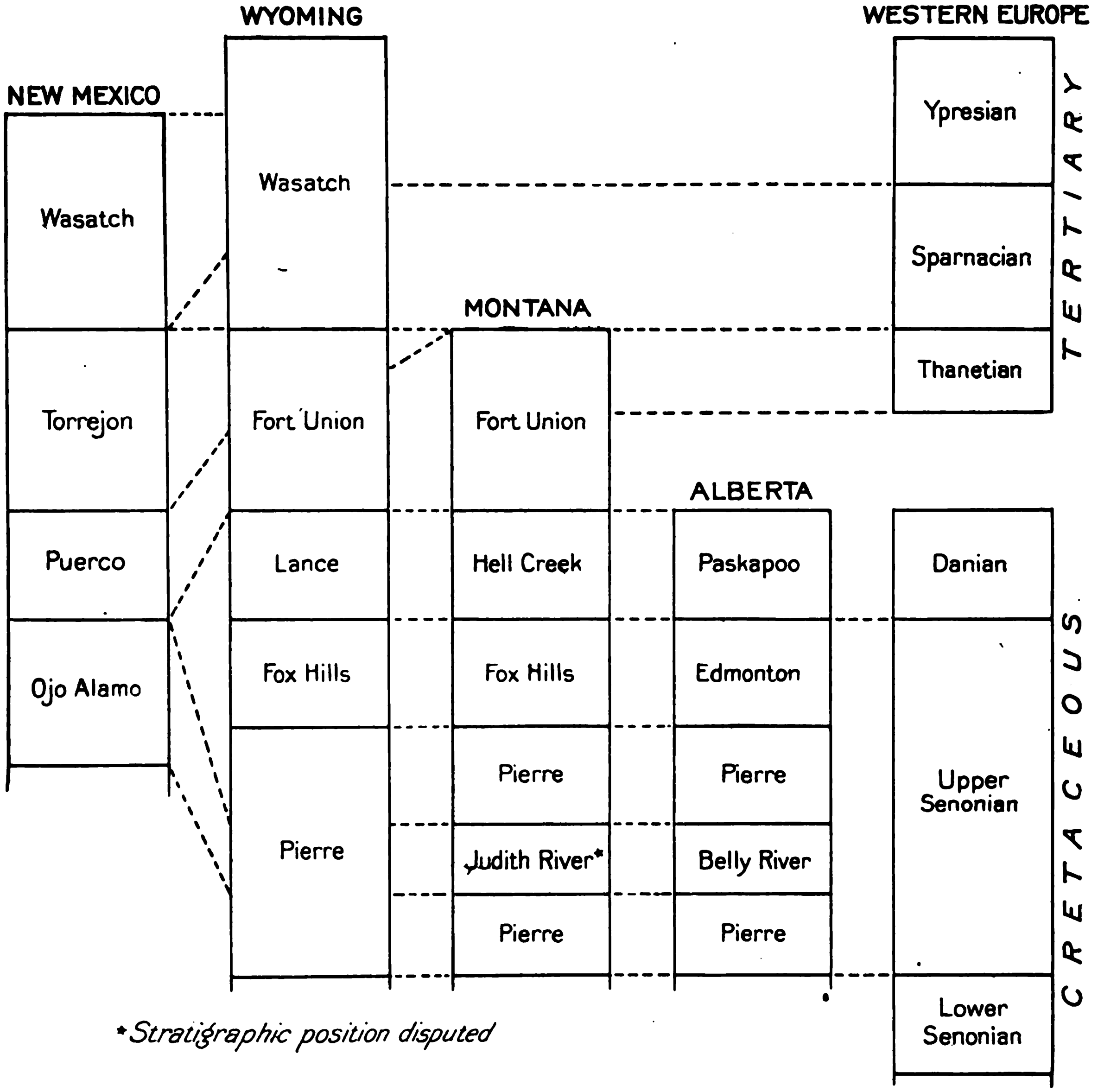

FIGURE 1.—Approximate correlations of typical formations of late Cretaceous and early Tertiary in Europe and western America, based on their vertebrate faunas. After W. D. Matthew, Geol. Soc. America Bull., vol. 25, p. 393, 1914.

The final paper of the symposium was presented by W. J. Sinclair [30] and later published under joint authorship with Walter Granger.

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[30] Sinclair, W. J., and Granger, Walter, Paleocene deposits of the San Juan Basin, N. Mex.: Am. Mus. Nat. Hist. Bull., vol. 33, pp. 297-316, 1914.

As the title indicates, the authors were concerned principally with the lower Eocene mammal-bearing formations and only incidentally with the underlying dinosaur-bearing beds. As this phase of the paper is treated at length under the discussion of the San Juan Basin (pp. 69–76) it need not be further considered here.

In May, 1914, after a prolonged discussion of all the lines of evidence then available, it was decided by the United States Geological Survey that, so far at least as its official publications are concerned, the Lance formation is to be classed as "Tertiary (?)" instead of "Cretaceous or Tertiary," as previously, and that the Arapahoe, Denver, Dawson arkose, and Raton formations, with which I believe the Lance formation to be in part synchronous, are to be classed as Eocene instead of Cretaceous.

One of the first places in which this newer interpretation of the position of the Lance formation appears was a paper by Bauer,[31] published in 1914. This paper presented the results of an examination of an area in northeastern Montana along the north border of the Fort Peck Indian Reservation. The only sedimentary formations present are the Lance and Fort Union. Concerning the line between them Bauer said:

> Owing to the absence of a sharp lithologic boundary between the formations and to the lack of exposures near the critical horizon in this field and also in the northern part of the reservation, the accurate mapping of the Lance-Fort Union boundary is impossible. In drawing the line shown on the map the known outcrops of somber-colored beds are considered to belong to the Lance, and those of yellow beds to the Fort Union. * * * Its [the Lance's] separation from the overlying Fort Union formation is thus based on its stratigraphic position and lithologic character. In these particulars it agrees with the Lance formation as recognized in other areas in eastern Montana and in North Dakota, where it is further characterized by a dinosaur fauna which has not been found in the Fort Union. Formerly the Survey considered the evidence of the age of the Lance so conflicting that it was ascribed to the Cretaceous or Tertiary, but recently the close correlation of the Lance flora with that of well-determined Tertiary formations of the Gulf coast, considered together with the mountain-making movements that are supposed to have immediately preceded the deposition of the strata, has led the Survey to assign the formation to the Tertiary (?) system.

A small coal area on the west side of Big Horn River, Mont., in the angle formed by its junction with the Yellowstone, was described by Rogers.[32] The strata examined are mainly referable to the Lance formation; concerning which Rogers said:

> The Lance formation in this area may be divided into two parts, namely, a coal-bearing member, which comprises the upper 250 feet, and a lower portion about 900 feet thick. This distinction is made partly on lithologic grounds and partly because of the slight difference in the fossils found in the two divisions.

In the same volume with the two papers just mentioned was one by Lloyd[33] on the lignite field of the Cannonball River region, N. Dak. The four principal sedimentary formations recognized were the Fox Hills sandstone, Lance, Fort Union, and White River (Oligocene). Concerning the Fort Union and Lance formations he said:

> The Fort Union formation, of the lower part of the Tertiary system (Eocene), which contains the greater part of the valuable lignite in the Dakotas and eastern Montana, embraces the surface rocks in the western and northwestern parts of the Cannonball River field. Underneath the Fort Union is a series of beds which are now tentatively classified as probably of early Tertiary age and which have been referred to the Lance formation. The upper 250 or 300 feet of this formation is in the field markedly different in lithologic character from the underlying more typical Lance and has been found at numerous places to contain the remains of a marine fauna which has not previously been known in this part of the stratigraphic section. These beds have been mapped separately and are herein designated the Cannonball marine member of the Lance formation. The underlying lower part of the Lance is of fresh-water origin and is composed of alternating beds of shale and sandstone which on erosion give rise to the badlands described above. Its thickness is approximately 400 feet.

The fauna of the Cannonball member was alluded to as follows: "In the Cannonball River field several collections of marine invertebrate fossils made from the Cannonball member * * * have been identified by T. W. Stanton as belonging to a modified Fox Hills fauna."

In 1915 Lloyd and Hares[34] described in considerable detail the areal distribution, lithologic character, and stratigraphic relations of the Cannonball member and argued for its probable Cretaceous age. They wrote:

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[31] Bauer, C. M., Lignite in the vicinity of Plentywood and Scobey, Sheridan County, Mont.: U. S. Geol. Survey Bull. 541, pp. 293, 315, 1914.

[32] Rogers, G. S., Geology and coal resources of the area southwest of Custer, Yellowstone and Big Horn counties, Mont.: U. S. Geol. Survey Bull. 541, pp. 316–328, 1914.

[33] Lloyd, E. R., The Cannonball River lignite field, Morton, Adams, and Hettinger counties, N. Dak.: U. S. Geol. Survey Bull. 541, pp. 243–292, 1914.

[34] Lloyd, E. R., and Hares, C. J., The Cannonball marine member of the Lance formation of North and South Dakota and its bearing on the Lance-Laramie problem: Jour. Geology, vol. 23, pp. 523–547, 1915.

> Field examinations by the writers and the paleontological determinations by Drs. Stanton and Knowlton during the years 1912 and 1913 show that in a large area west of Missouri River in North and South Dakota the Lance formation consists of two distinct parts—a lower nonmarine part containing a flora very similar to if not identical with that of the Fort Union, and an upper marine member containing a fauna closely resembling but not identical with that of the Fox Hills sandstone. This upper part, on account of its peculiar fauna, has been mapped separately and named the Cannonball marine member of the Lance formation. Farther west nonmarine beds bearing lignite and occupying a similar stratigraphic position have been named the Ludlow lignitic member of the Lance.

After describing the areal distribution and giving a number of sections of the strata, they proceeded to a discussion of interrelationships. The fauna of the Cannonball was studied by T. W. Stanton, who wrote concerning it as follows:

> The fauna of the Cannonball member of the Lance may now be characterized as a modified Fox Hills fauna. It contains a considerable proportion of undescribed species of Cretaceous affinities, and it is noteworthy that a number of the most common Fox Hills species have not been discovered in this fauna. * * * In this list of about 40 forms there are 21 named species and varieties, of which 15 occur in the Fox Hills, 4 occur in the Pierre, and 5 were originally described from rocks now known to belong to the marine member of the Lance. One species, *Corbicula cytheriformis*, was described from the Judith River formation and is known in the Mesaverde formation and the Lance of other areas.

After presenting and weighing the several lines of evidence that may be used in fixing the age of the Cannonball, these authors concluded as follows:

> A recent detailed consideration of all the evidence has led to a decision by the United States Geological Survey that the Denver and Arapahoe, Dawson, and Raton formations in Colorado and New Mexico all be placed in the Tertiary system. This decision was based primarily on the correlation of these formations with the Wilcox formation of the Gulf region on the evidence of their fossil floras and also on the consequent correlation of the unconformities in the two regions. Although the Lance formation is believed to be of the same age as the Denver, Raton, and "Upper Laramie," it is classified by the United States Geological Survey as Tertiary (?), the doubt being thus expressed on account of the Cretaceous character of the Cannonball marine fauna. The writers believe that greater weight should be given to the evidence of the marine faunas and the dinosaurs, and that, in view of the strong evidence presented by these faunas, the correlations made on the basis of fossil floras should not be considered as conclusive.

In a final footnote they added that "further studies on the Lance problem have strengthened the conviction of the writers that the Lance is Cretaceous."

FORT UNION FORMATION.

The early history of the Fort Union formation, or "Great Lignitic," as it was at first called, has been sufficiently set forth in the preceding pages. In fact, it was not until the Laramie was established that the element of discord was introduced which gave rise to so much subsequent discussion and difference of opinion. Most of the geologists and paleontologists who had studied the Fort Union contended for its Tertiary age, and Newberry, who investigated the flora, was at first inclined to refer it to the Miocene. It appears that Hayden was in the end more or less responsible for promulgating what has since been accepted as an erroneous view regarding the relation of the Fort Union to the Laramie. When the Laramie was adopted by Hayden, he made it include or at least be equivalent to the Fort Union, as the following statement shows:[35]

> If objection is made to the use of the term "Lignitic" group, I would say that in this work it is restricted to a series of coal-bearing strata lying above the Fox Hills group, or Upper Cretaceous, and these are embraced in the divisions Laramie and Fort Union.

On the same page Hayden continued:

> As far back as 1859 it was my belief, founded on what appeared sufficient evidence, that the sequence between the well-characterized Cretaceous strata and those of the Lignite group, as defined at that time, was continuous, and that the chasm that was supposed to exist between the Cretaceous and the Tertiary epoch would be found to be bridged over.

He then proceeeded to quote Dr. C. A. White, who, he said,

> had made a critical examination of these formations during the past season, and he says that his investigations have freely confirmed the views expressed by me some years ago and indicated by the paleontological studies of Mr. Meek, that the Fort Union beds of the upper Missouri River are the equivalent of the Lignitic formation as it exists along the base of the Rocky Mountains in Colorado.

Inasmuch as the Fort Union was regarded as equivalent to the lignite-bearing beds east of the mountains in Colorado, which fell within the typical areas included by King in the Laramie, it of course followed that the

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[35] Hayden, F. V., letter of transmittal for Lesquereux's "Tertiary flora": U. S. Geol. Survey Terr. Rept., vol. 7, p. iv, 1878.

Fort Union was regarded by Hayden as of the same age as the Laramie, if not, indeed, included in it.

As is well known, Hayden originally considered all of his Laramie (Laramie and Fort Union) as of Tertiary age, but his latest conclusion was that the whole mass was of a transitional character—that is, it formed beds of passage between the Cretaceous and Tertiary. Newberry[36] in commenting on this conclusion said: "It is easy to see that this result was inevitable, after he had united an Upper Cretaceous with a Tertiary formation under one name."

Clarence King, however, did not accept Hayden's reference of the Fort Union to the Laramie. When preparing the final volume on the systematic geology of the vicinity of the fortieth parallel, he had before him Lesquereux's "Tertiary flora," above quoted, and after admitting that he had never visited the locality and could not therefore "speak with any definiteness," he added (p. 353):

> I consider it worth while to point out here a noticeable ambiguity in its evidence. Cope, in his introduction to his volume on the Cretaceous, cites dinosaurs as coming from the Fort Union, from which he refers the fauna to the Mesozoic series. On the other hand, the characteristic plant life of the country differs entirely from that described by Lesquereux in Volume II, Tertiary flora. It is noticeable that he nowhere describes in that volume any of the plants from the classic Fort Union locality, a series which has been studied by Newberry and which contains not only a general resemblance but some actual species identical with the Miocene of Greenland and northern Europe. * * * Until fresh evidences of the stratigraphical relations, and a full discussion of the fauna of the whole series of rocks at Fort Union is fully made, a definite correlation is impossible, and at present writing the entire difference between the plants at Fort Union and anything in Colorado or Wyoming that is of value at all suggests that they can not be related to any of the southern groups. I apprehend that the plant horizon at Fort Union will be found to be nothing but a northward extension of the White River Miocene.

King's reference of the Fort Union to the White River has not of course been sustained, but otherwise his suggestions have proved to be wonderfully near the truth.

C. A. White did much to merge the Fort Union in the Laramie. In fact, in what was perhaps his last utterance[37] on the subject he said:

> The localities at which Laramie strata were first studied by geologists were often distant from one another, and they were not then recognized as constituting one great formation. * * * These deposits consequently received a different name in each district. They thus have received such names as Fort Union group, Judith River group, Lignitic group, and Bitter Creek series. The term Lignitic soon came to be applied to the strata of several districts which are now included in the Laramie.

It was not possible, according to White, to distinguish between Fort Union and Laramie by the invertebrates, and this view was generally entertained by paleontologists for many years thereafter.

The influence of what are now known to have been the erroneous views of Hayden, White, and others is well shown in Ward's elaborate paper "Synopsis of the flora of the Laramie group,"[38] in which he included in the Laramie not only the Fort Union but also beds now known to belong to the Montana, Arapahoe, Denver, Lance, and other formations. It should not be presumed, however, that he failed to note that there were striking differences between the typical Laramie flora and that of the Fort Union, but he was misled by the opinion of the time that all the formations he included formed an unbroken sedimentary sequence. His investigation was undertaken primarily to ascertain the bearing of the plants on the question of the age of the Laramie, but naturally it failed in reaching definite results. In this paper Ward described many new forms from a great many localities and horizons, though so many were from the Fort Union that Newberry,[39] in commenting on it, said: "But his monograph as a whole is simply an important contribution to what was before known of the Fort Union flora."

It is undoubtedly to J. S. Newberry that most credit is due for keeping alive and insisting upon the distinctness of the Fort Union from the Laramie. From the beginning of his studies of the material collected by Hayden in the fifties until his death he maintained its Tertiary age. In the paper above quoted he said:

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[36] Newberry, J. S., The Laramie group: New York Acad. Sci. Trans., vol. 9, p. 3, 1889 (reprint).

[37] White, C. A., Correlation papers—Cretaceous: U. S. Geol. Survey Bull. 82, p. 147, 1891.

[38] Ward, L. F., U. S. Geol. Survey Sixth Ann. Rept., pp. 399-557, pls. 31-65, 1886.

[39] Newberry, J. S., The Laramie group: New York Acad. Sci. Trans., vol. 9, p. 4, 1889 (reprint).

> Whether the Laramie is Cretaceous and the Fort Union Tertiary are other questions, but they are certainly distinct from each other—distinct in the general botanical facies of their floras as well as in the absence of common species. That the Fort Union is Tertiary there can be no reasonable doubt; it has many species in common with the recognized Tertiary in the Canadian provinces of North America, in Greenland, and in the British islands, and it contains some plants which are living at the present day, such as *Onoclea sensibilis*, *Taxodium distichum*, *Corylus americana*, *C. rostrata*, etc. Moreover, the grouping of the plants composing it gives it a facies which enables one to recognize it at a glance. The abundance of species and specimens of *Populus*, *Viburnum*, and *Corylus* imparts to it an aspect as different from that of the flora of the Laramie as are the recent floras of Europe and America from each other.

In his last published utterance on this subject Newberry [40] made the following emphatic statement:

> The floras of the Laramie and Fort Union groups are totally distinct, and these formations should be referred to different geological systems—the Fort Union to the Tertiary and the Laramie to the Cretaceous.

In 1896 W. H. Weed [41] published a short paper entitled "The Fort Union formation," in which, after briefly reviewing the early history of the Fort Union and Newberry's contention that it should be referred to the Tertiary, he described the geologic section in the vicinity of the Crazy Mountains, in Montana, where, he said, the Fox Hills, Laramie, Livingston, and Fort Union formations are superimposed. This view I hold to be in the main correct, although, as will be shown later in the discussion of the Livingston formation, there are many who do not accept it. In any event, it was made plain that the Fort Union formation of this region was above beds that should properly be referred to the Laramie or were in its position.

More than 25 years ago I became convinced of the correctness of Newberry's conclusion as to the Tertiary age of the Fort Union formation, and in many papers and reports published since that time I have consistently adhered to this view. It is perhaps not necessary further to allude to these papers, nor is it possible to fix an exact date on which the Fort Union became generally accepted as a Tertiary unit. The term with the present accepted application has been in current use for a dozen years or more and apparently is no longer seriously questioned.

As an example of the completeness of this change mention may be made of the treatment of the Fort Union in the reports of the Geological Survey of North Dakota. Thus, in the third biennial report of the State geologist, published in 1904, the term Fort Union does not occur, all beds under consideration being referred to the Laramie, but in the fifth biennial report, issued in 1908, the conditions were reversed and the Laramie was no longer accepted as present, all the beds being referred to the Fort Union or Lance. In a geologic map of North Dakota, published by A. G. Leonard [42] in 1913, the Laramie was not recognized, but nearly half of the State was shown to be covered by the Fort Union formation. In the text accompanying this map Leonard said:

> The Fort Union is one of the best-known formations of the Northwest. It covers a vast area east of the Rocky Mountains, stretching from Wyoming to the Arctic Ocean in the valley of the Mackenzie River and including part of several Canadian provinces, much of western North Dakota, eastern Montana, northwestern South Dakota, and central and eastern Wyoming.

"LARAMIE" IN THE CANADIAN PROVINCES.

It appears that as early as 1873 George M. Dawson, while acting as geologist to the British North American Boundary Commission, noted the presence at certain points along the international boundary of lignite-bearing beds that he identified with the "Great Lignitic or Fort Union group" of Hayden, as exposed along Missouri River. This view was affirmed the following year in an article on the "Lignite formations of the West," [43] in which this statement was made:

> In view of the evidence of the preponderant animal and vegetable forms, it seems reasonable to take the well-marked base of the Lignite series as that of the lowest Tertiary, at least at present. The formations described belong to this lowest Tertiary, being in fact an extension of Hayden's Fort Union group, and from analogy may be called Eocene.

So far as I have been able to ascertain, the term Laramie was first applied in the Canadian provinces also by Dawson [44] in his "Report on an exploration from Fort Simpson, on the Pacific coast, to Edmonton, on the Saskatchewan, embracing the northern part of British Columbia and the Peace River country." In discussing the Peace River section he several times alluded to the Laramie as following the Fox Hills conformably, but whether he intended to refer it to the Cretaceous or the Tertiary is not quite clear, though in a "comparative table of Cretaceous rocks" he made the so-called Laramie equivalent to the Fort Union and Judith River beds of Nebraska and Missouri rivers and also to the "Lignite Tertiary" of the forty-ninth parallel.

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[40] Newberry, J. S., The Laramie group: Geol. Soc. America Bull., vol. 1, p. 525, 1890.

[41] Am. Geologist, vol. 12, pp. 201-211, 1896.

[42] The geological map of North Dakota: North Dakota Univ. Quart. Jour., vol. 4, No. 1, October, 1913.

[43] Dawson, G. M., Canadian Naturalist, new ser., vol. 7, p. 252, 1874.

[44] Dawson, G. M., Canada Geol. Survey Rept. Progress for 1879-80, pp. 127-134B.

A year or two later, in his preliminary paper on the "Geology of the Bow and Belly River region," Dawson [45] took occasion to define the use of Laramie as follows:

> The term Laramie is used in a general sense for the Upper Cretaceous or lower Eocene beds which overlie the Fox Hills series (Cretaceous No. 4). It is not intended by its use to differentiate the beds so named from those of the Judith River and Fort Union series, with which they may be found to blend as the intervening district is more completely explored.

In describing the general arrangement of the beds in the Belly River region, Dawson gave the following section:

Laramie.	Beds of the Porcupine Hills, chiefly thick-bedded sandstones and some shales.
	Willow Creek series. Reddish and purplish clays with gray and yellow sandstones.
	St. Mary River series. Sandstones, shales, and clays of general grayish or grayish-green colors.
	Yellowish sandstones and shaly beds, with a mingling of fresh-water and brackish or marine mollusks.
Fox Hills.	Yellowish sandstones, with some shales, irregular in thickness and character. Mollusks all marine.
Pierre.	Blackish and lead-colored shales, etc.
Niobrara (?).	Belly River series.

The complete report on the "country in the vicinity of Bow and Belly rivers, Northwest Territory," was published by Dawson [46] in 1885. In this report the descriptions of the "Laramie" are amplified and the thickness given. Thus the Porcupine Hills beds are given a thickness of 2,500 feet, the Willow Creek beds 450 feet, and the St. Mary River beds 2,800 feet.

Dawson [47] continued his explorations in the Canadian Rocky Mountains, his report published in 1886 including that portion from the international boundary northward to the headwaters of Red Deer River. In this report he alluded many times to the presence of the "Laramie" but always with the signification already given to it.

In the same volume R. G. McConnell [48] published a "Report on the Cypress Hills, Wood Mountain, and adjacent country in Assiniboia," in which he referred to the current uncertainty regarding the position of the "Laramie" and adopted the view that it is probably transitional between Cretaceous and Tertiary. In the Cypress Hills and vicinity, according to McConnell, it is apparently conformable to the Fox Hills sandstone and of small thickness, but in the Wood Mountain region it was found to be better represented and in some places capable of being divided into three "somewhat dissimilar groups." He quoted extensively from Dawson's report of 1875.

In the following year (1887) J. B. Tyrrell [49] presented an important paper on northern Alberta and adjacent districts in Assiniboia and Saskatchewan, in which he made a complete realinement of the "Laramie," although still using it as a group term. He established the Edmonton and Paskapoo series in substitution for the names proposed by Dawson. As these terms have now come into wide usage the formations may be described at some length.

The Edmonton series, which comprises the lower 700 or 800 feet of Dawson's St. Mary River series, was described as follows:

> This is perhaps, on the whole, the most characteristic series of the entire region, for though its thickness, wherever determinable, was never found to exceed 700 feet, the horizontal position of the strata causes it to underlie a very large extent of country.

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[45] Dawson, G. M., Canada Geol. Survey Rept. Progress for 1880-1882, p. 2B, 1883.

[46] Dawson, G. M., Canada Geol. Survey Rept. Progress for 1882-1884, pp. 1-159C, 1885.

[47] Dawson, G. M., Canada Geol. and Nat. Hist. Survey Ann. Rept., new ser., vol. 1, for 1885, pp. 1-169B, 1886.

[48] Idem, pp. 1-85C.

[49] Canada Geol. and Nat. Hist. Survey Ann. Rept., new ser., vol. 2, for 1886, pp. 1-176E, 1887.

> It consists generally of whitish or light-gray clay and soft clayey sandstone, weathering very rapidly, with more or less rounded outlines. In some places, as on Red Deer River and in the Hand Hills, it is seamed with a great number of beds of ironstone, which with thin beds of lignite and lignitic shale give a definite banded character to all the escarpments. It also contains a great number of nodules of compact ironstone, which are often perched on little pinnacles cut out of the soft sandstone. In the northern portion, especially along the North Saskatchewan, the banded appearance is seldom seen, though with the exception of a smaller quantity of ironstone, the rock has very much the same character as further south.
>
> This is essentially the coal-bearing horizon within the district, all the coal found east of the foothills, except probably the seams on the upper North Saskatchewan and at Egg Creek, being of this age. The top of the formation is marked by an extensive coal deposit seen first in the Wintering Hills as a thin bed of carbonaceous shale, but on being traced northward is found to thicken very greatly, till on the North Saskatchewan, near Goose Encampment, it has a thickness of 25 feet. The bottom of the series lies conformably on the Pierre shales, without any sharp line of demarcation between the two. In fact, the shales gradually lose their massive character and change almost insensibly into thin beds, which are of decidedly brackish-water origin. In the Pierre remains of land plants and animals are very rare, while here traces of land plants become fairly plentiful, and on Red Deer River dinosaurian bones are met with in great abundance, showing, with the presence of estuarine shells, the partly land-locked character of the area within which the beds were deposited.

Toward the west the Edmonton gradually disappears beneath the overlying beds of the Paskapoo, and, Tyrrell added,

> In many places the junction of the Pierre and Laramie was plainly seen, the sandstones of the Paskapoo series appearing to rest conformably on the shales of the Pierre, so that the Edmonton series seems to thin out and disappear between its western outcrop and the eastern edge of the foothills.

The Edmonton was identified with the lower division of the Laramie in the Cypress Hills region, described by McConnell, and with the Wapiti River group of Dawson in the Peace River region.

The Paskapoo series was said to include "all the Laramie rocks lying above those of the Edmonton series" and to embrace Dawson's "Porcupine Hills and Willow Creek series and all but the lowest 700-900 feet of his St. Mary River series." The maximum thickness noted was 5,700 feet. The beds, according to Tyrrell,

> consist of more or less hard light-gray or yellowish, brownish-weathering sandstone, usually thick bedded but often showing false bedding; also of light bluish-gray and olive sandy shales often interstratified with bands of hard lamellar ferruginous sandstone and sometimes with bands of concretionary blue limestone, which burns into excellent lime. * * * The whole series, as shown by its invertebrate fauna, is of fresh-water origin.

The lists of fossils given by Tyrrell show clearly that the Paskapoo is to be correlated with the Fort Union of the Missouri River region.

As regards the age of the "Laramie," Tyrrell concluded, after briefly reviewing the evidence, that

> it seems reasonable to place the close of the Cretaceous epoch at the time of the deposition of the topmost beds of the Edmonton series, and that the Tertiary epoch began with the commencement of the Paskapoo period, during which a great thickness of sandstones and sandy shales was laid down without any apparent break or unconformity.

In the same volume as that containing Tyrrell's report George M. Dawson[50] presented certain "Notes to accompany a geological map of the northern portion of the Dominion of Canada, east of the Rocky Mountains," in which he stated that in the valley of Mackenzie River near the mouth of Bear Lake River Richardson found rocks which he referred to the "Lignite formation" but which "with little doubt represent the series now known as the Laramie."

In the subsequent annual reports of the Canada Geological Survey the "Laramie" continued to receive occasional mention, but no extensive papers in which it was involved were published, and the usage of the term continued about as established by Tyrrell for central Alberta. A number of papers were published from time to time by Sir William Dawson, J. F. Whiteaves, E. D. Cope, L. M. Lambe, and others on different phases of the paleontology of the Canadian "Laramie." Thus, as early as 1885 Whiteaves[51] published a "Report on the Invertebrata of the Laramie and Cretaceous rocks of the vicinity of the Bow and Belly rivers and adjacent localities in the Northwest Territory," in which he described some 35 species from the so-called Laramie of Alberta and the Souris River district, this being a paleontologic supplement to Dawson's paper on the same region already noted. He also described many species from the Belly River series, of which he said:

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[50] Canada Geol. and Nat. Hist. Survey Ann. Rept., new ser., vol. 2, for 1886, pp. 18, 19R, 1887.

[51] Whiteaves, J. F., Contr. Canadian Paleontology, vol. 1, pt. 1, 1885.

> Judging from their respective invertebrate faunae, it would seem impracticable to separate the "Belly River series" from the Laramie and more especially from the "Judith River group" on purely paleontological evidence.

Dawson published several papers on the flora of the "Laramie." In a paper on the Cretaceous and Tertiary floras of British Columbia and the Northwest Territory[52] he gave lists of "Laramie" plants from several localities. He considered the so-called Laramie as equivalent to the Fort Union, and the plants mentioned undoubtedly bear this out. In 1885, in his paper on the Mesozoic floras of the Rocky Mountain region of Canada,[53] he discussed the Belly River and so-called Laramie series, which he then failed to differentiate. He divided the "Laramie" into three "groups"—the "Lower Laramie," which embraced the St. Mary River series of George M. Dawson; the "Middle Laramie," or Willow Creek series of Dawson; and the "Upper Laramie," or Porcupine Hill series of Dawson. To judge from the lists of plants given, it would seem that there had been some mixture of horizons when the collections were made.

Dawson's third paper, on the fossil plants of the Laramie formation of Canada,[54] introduced still another set of terms. He stated that the "Laramie" of Canada occurs in two large areas west of the 100th meridian and separated from each other by a tract of older Cretaceous rocks. The eastern of these areas extends for some distance along the United States boundary between the 102d and 109th meridians and northward nearly to the parallel of 51°. Here, he said, the lowest beds of the "Laramie" rest on Fox Hills and are overlain by Miocene. He continued:

> They are undoubtedly continuous with the Fort Union group of the United States geologists on the other side of the international boundary, and they contain similar fossil plants. They are divisible into two groups—a lower, mostly argillaceous, and to which the name of "Bad Lands beds," may be given from the "badlands" of Wood Mountain, where they are well exposed, and an upper, partly arenaceous member, which may be named the Souris River or Porcupine Creek division. In the lower division are found reptilian remains of Upper Cretaceous type, with some fish remains more nearly akin to those of the Eocene.

The western area is of still larger dimensions and extends along the eastern base of the Rocky Mountains from the United States boundary to about the 58th parallel of latitude and thence eastward to the 111th meridian. In this area three divisions of the beds are made:

> (1) The Lower Laramie, or St. Mary River series, corresponding in its character and fossils to the Lower or Bad Lands division of the other area; (2) a middle division, the Willow Creek beds, not recognized in the other area; (3) the Upper Laramie or Porcupine Hills division, corresponding in fossils and to some extent in mineral character to the Souris River beds of the eastern area.

The paper enumerated 51 forms of plants, of which 10 were found in the "Lower Laramie" and the remainder in the "Upper Laramie," with about 8 in common. It is essentially a Fort Union flora.

Several years later Dawson[55] published another short paper dealing mainly with plants from Mackenzie River, which he showed are to be identified with the Fort Union.

In 1893 Whiteaves[56] delivered a presidential address before the Royal Society of Canada, on "The Cretaceous system of Canada," which was mainly an enumeration of the fossil forms that had been recorded from the several members of the Cretaceous. Although he did not specifically so state, it is evident that he included in the "Laramie" both the "Lower Laramie" and "Upper Laramie" of previous writers, and of course it was all regarded as Cretaceous.

In 1908 D. P. Penhallow[57] presented an elaborate "Report on Tertiary plants of British Columbia," which was based primarily on collections made by L. M. Lambe in 1906 but which was made to include all previous work by Dawson and others within this area. If Penhallow had taken occasion to revise the earlier work, this could have been made a very valuable contribution, but unfortunately he made no attempt at revision and the lists were compiled without change. The "Laramie" here was said to include only the "Upper Laramie" (Paskapoo of Tyrrell), which was made synonymous with Fort Union, lower Eocene, and "Lignite Tertiary." The conclusion of Sir William Dawson that the "Upper Laramie" is undoubtedly of Tertiary age was confirmed.

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[52] Roy. Soc. Canada Trans., vol. 1, sec. 4, pp. 15-34, 1883.

[53] Idem, vol. 3, sec. 4, pp. 1-22, 1885.

[54] Idem, vol. 4, sec. 4, pp. 19-34, 1887.

[55] Dawson, William, On fossil plants from the Mackenzie and Bow rivers; Roy. Soc. Canada Trans., vol. 7, sec. 4, pp. 69-74, 1889.

[56] Whiteaves, J. F., Roy. Soc. Canada Trans., vol. 9, sec. 4, pp. 1-19, 1893.

[57] Canada Geol. Survey Mem. 1013, pp. 1-167, 1908.

For a decade or more after the publication of the papers above mentioned very little investigation appears to have been prosecuted in the areas covered by the so-called "Laramie," and the subject remained practically as left by the earlier writers. Then, in a valuable paper published in 1909, by D. B. Dowling,[58] on the "Coal fields of Manitoba, Saskatchewan, Alberta, and eastern British Columbia," the "Laramie" was said to embrace the Edmonton and Paskapoo with the significance attached by Tyrrell, from whom extensive quotations were taken.

Dowling's report was summarized in the report of the Director of the Canadian Geological Survey,[59] who gave a full-page table of correlations of the formations involved, in which the "Laramie" was assigned the interpretation adopted by Dowling.

In the following year Dowling[60] published a short bulletin on the Edmonton coal field, Alberta, which was devoted mainly to the wonderfully rich coal deposits of the Edmonton formation. The term "Laramie" was not mentioned in this bulletin, but the Edmonton was "classed with the undoubted Cretaceous beds below and represents the upper member of this series." The plants listed, if correctly identified, indicate a mixture of Cretaceous and Tertiary (Fort Union) types.

In 1913 Malcolm[61] published a paper on the "Oil and gas prospects of the Northwest Provinces of Canada," in which the Edmonton and Paskapoo were grouped under the "Laramie" with the following qualification:

> In placing under this heading the formations to be described, it is not the intention of the author to indicate in this way the precise age of the formations or to indicate the dividing line between the great geological systems. The grouping is for convenience in description and for the purpose of showing the stratigraphic relations of the formations.

There seems, however, to have been no general understanding or usage, and in the Summary Report of the Canada Survey for 1913, published in 1914, D. B. Dowling[62] had a short paper on the Sheep River gas and oil field of Alberta, in which the Paskapoo was put into the Tertiary and the Edmonton into the Cretaceous, but the term "Laramie" was not used.

In the same volume Bruce Rose[63] had a short paper on the Willowbunch coal area, Saskatchewan, in which he stated that the only rocks exposed in this area are to be referred to the Fort Union formation, which is essentially the same as the Paskapoo formation of Alberta and is practically continuous with the Fort Union of the United States.

Barnum Brown[64] published a paper in 1914, already mentioned in another connection, which presented the results of his studies for a number of years of the Edmonton formation of the Red Deer River region of Alberta. The splendid section exposed for a distance of 300 miles along this river cuts successively through the Paskapoo and Edmonton and well down into the Pierre. The classification adopted was "the latest determination of these formations by the Canadian Geological Survey" and grouped the Paskapoo and Edmonton under the "Laramie." According to Brown, the Edmonton wherever observed was found resting in apparent conformity on the Pierre. The relations between the Edmonton and the overlying Paskapoo were described by Brown as follows:

> Near the mountains these beds (Paskapoo), according to Tyrrell, appear to rest conformably on the Pierre shales. On the Red Deer River and elsewhere they are separated from the underlying brackish-water Edmonton beds by a widely distributed coal seam of varying thickness. No other sign of unconformity has been recognized, but a considerable time elapsed between the close of the Edmonton and the beginning of the Paskapoo—a time interval represented by all or the greater part of the Lance. No dinosaurs are found in these beds, and the abundant and varied dinosaurs of the underlying Edmonton formation are an older facies than those of the Lance.

The several lines of paleontologic evidence were discussed somewhat at length, especially the vertebrate evidence, in which Brown is a specialist. Concerning the dinosaur fauna he said:

> The vertebrate fauna is distinct from that of the Lance, and few species are common to the two formations. Most of the Edmonton genera are structurally more primitive than those of the Lance, and several genera not found in the Lance are common to the Judith River. The faunal facies, as a whole, is intermediate but closer to that of the Judith River formation than to the Lance. * * * The

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[58] Canada Geol. Survey Pub. 1035, pp. 38-43, 1909.

[59] Canada Geol. Survey Summary Rept. for 1909, p. 38, 1910.

[60] Dowling, D. B., Canada Geol. Survey Mem. 8E (Pub. 1115), 1910.

[61] Malcolm, Wyatt, Canada Geol. Survey Mem. 29E, 1913.

[62] Canada Geol. Survey Summary Rept. for 1913, p. 142, 1914.

[63] Idem, p. 153.

[64] Cretaceous Eocene correlation in New Mexico, Wyoming, Montana Alberta: Geol. Soc. America Bull., vol. 25, pp. 355-380, 1914.

dinosaur fauna forms a series of successive genera, the phyletic relationship of which is determined by the evolutionary development of skeletal parts, and there is no break in this series from its first appearance low down in the Cretaceous to the final disappearance of the entire group in what we propose to call the close of the Cretaceous.

The invertebrates were submitted to T. W. Stanton, who commented as follows:

> I have recently examined your invertebrates from the Edmonton and Paskapoo formations of Alberta. Those which you have already sent from the Edmonton beds include several lots of brackish-water shells, with a slighter mixture of marine forms (*Lunatia*), and several lots of purely fresh-water shells. The brackish-water collections are certainly Cretaceous and consist of species which all occur either in identical or very closely related forms in both the Judith River and in the brackish-water bed which occurs at the top of the Fox Hills and the base of the Lance.
>
> The fresh-water collections contain no species characteristic of either the Judith River or the Lance, and while some of them, like *Goniobasis tenuicarinata*, occur in the Lance, the general aspect of the fossils is somewhat more suggestive of [Fort Union than of anything earlier. It should be remembered, however, that Whiteaves has reported a number of] Fort Union species as occurring in the Belly River beds of Alberta, and it may be that more of these types than we have supposed range down as low as the Judith River.[65]

The fossil plants were studied by Arthur Hollick and me and pronounced to be of Fort Union age, though a small collection from the lower part of the Edmonton submitted to me at a later date appeared to be of Cretaceous affinity.[66]

As regards the age of the Edmonton, Brown said:

> The Edmonton formation differs greatly in lithologic character from the Fox Hills, which occupies the same relative position in the United States, where it is a sandstone formation, but I believe it to have been, in part at least, synchronous with the Fox Hills. It may possibly be correlated with the Laramie, according to its original definition.

In a later paragraph he added:

> The strata (Edmonton) are of marine and brackish-water origin and everywhere conformably overlie the marine beds below. The shale series shows an interrupted successive sedimentation from purely marine conditions at the base, through brackish water during most of the period, with a gradual freshening toward the top. This formation fulfills the original definition of the term Laramie.[67]

According to Brown, the Paskapoo formation, as already mentioned, was conformable on the Edmonton, though he thought there was a time interval between them, as shown by the absence of all or nearly all of the Lance formation. The Paskapoo, although containing no dinosaurs, has a small mammal fauna, which, he said, "is more varied than that of the Lance and is comparable to it."

A late word on the correlation of the Edmonton with beds in the United States is spoken by Eugene Stebinger[68] in his paper on "The Montana group of northwestern Montana." The uppermost member of the Montana group recognized was here called the Horsethief sandstone, which is the equivalent of the Fox Hills as identified by G. M. Dawson in Alberta. Stebinger's conclusion was as follows:

> Above the Horsethief sandstone in the section on Two Medicine River there are light-colored soft clayey and sandy strata, already referred to as of continental origin, that are identical in appearance with the Belly River and Judith River strata. Although these rocks are younger than Montana in age, they deserve mention here because they seem to complete for a third time a cycle of sedimentation proceeding from purely marine to fresh-water or continental conditions. The first of these cycles is from the marine Colorado shale, through Virgelle sandstone, to the strata of continental origin in the lower part of the Two Medicine formation; the second is from the marine shale of the Claggett, through the sandstone in its upper part, to strata, also of continental origin, comprising the Judith River formation; and the third is from the marine Bearpaw, through the Horsethief sandstone, to the continental deposits above that sandstone. The relations in each cycle between the continental deposits and the underlying sandstone seem to be identical. The strata are apparently perfectly conformable, and the impression is very strong that the same conditions ruled in each transition from marine to land conditions, or, in other words, the strata above the Horsethief sandstone are physically as closely related to the Bearpaw shale as the Judith River formation is to the Claggett or the Two Medicine formation to the Colorado shale. Now, these strata of continental origin above the Horsethief sandstone constitute the St. Mary River beds of Dawson, which occupy the same position in the geologic column as the Edmonton formation of central Alberta and approximately that of the Lance formation of Wyoming.

"LARAMIE" AND LIVINGSTON FORMATIONS IN MONTANA.

The area in the vicinity of Livingston, Mont., and extending thence southward to the northern border of the Yellowstone National Park and northward around the Crazy

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[65] The words in brackets, which were omitted from Brown's paper through an error in transcription or in printing, were supplied by Mr. Stanton in a personal communication to me.

[66] Knowlton, F. H., Cretaceous-Tertiary boundary in the Rocky Mountain region: Geol. Soc. America Bull., vol. 25, p. 337, 1914.

[67] Brown was in error on this point, for, according to King's original definition, the Laramie is the "uppermost member of the conformable Cretaceous series above the Fox Hills."

[68] U. S. Geol. Survey Prof. Paper 90, p. 68, 1914.

Mountains has proved to be of much geologic interest. A number of short reports and newspaper and magazine articles regarding this area had appeared prior to 1871, but they were devoted mainly to descriptions of scenic features and contained little or no geologic information. In 1871 F. V. Hayden[69] began his investigations in the Yellowstone National Park and incidentally described the geology of the area between Fort Ellis and what is now the north line of the park. He noted the presence of both Cretaceous and Tertiary rocks in the area. In the same report[70] Lesquereux described the fossil plants obtained by the Hayden parties, referring those found 6 miles above Spring Canyon; on High Ridge, about 10 miles west of Hot Springs; and at Yellowstone Lake, among basaltic rocks, to the Eocene, while those from the mouth of Spring Canyon were not definitely placed.

In the following year the exploration of the Yellowstone National Park was continued by the Hayden Survey, and A. C. Peale[71] reported on the geology of the area between Fort Ellis and the Yellowstone Valley and thence up the Yellowstone to the park. He also noted the presence of Cretaceous and Eocene, the latter on the basis of the determinations of the fossil plants by Lesquereux.

In 1878 Lesquereux[72] published his "Tertiary flora," in which he brought together all the species of plants—329 in number—which he then considered as belonging to the flora of the "Lignitic." The beds at the localities near Fort Ellis, above Spring Canyon, and at Yellowstone Lake he referred to his so-called "first group," which he considered as of Eocene age. The species from the locality at the mouth of Spring Canyon were not alluded to, as they were, at least by inference, considered as Cretaceous.

In 1886 the final report of the Tenth Census of the United States relating to the mineral resources, exclusive of the precious metals, was published under the general direction of Raphael Pumpelly. It embraced reports by Waldemar Lindgren[73] and George H. Eldridge[74] on the geology and coal resources of Montana, and each contained data bearing more or less directly on the present problem. Lindgren reported especially upon the section from the Bull Mountains to Musselshell River and referred the immense thickness of nearly 10,000 feet of beds above the Fox Hills to the Laramie, which he divided into a "Lower Laramie" and an "Upper Laramie," the latter being recognized as the Fort Union.

The so-called Bozeman coal field was described by Eldridge. He presented a section of the rocks (LVI, fig. 2) through this field, beginning with the Jurassic and including the Dakota, Benton, and Niobrara and of course the coal-bearing rocks. The coal-bearing rocks were not definitely referred to the Laramie, though they were obviously considered as belonging in it. As regards the stratigraphic relations of the coal measures, Eldridge wrote as follows:

> There is another most important peculiarity in the behavior of the principal coal seams, noticed in the eastern portion of the field. The surface of the ground on which the coal bed was originally laid down is most irregular. For a length of 2 miles at least, and for an undetermined width, but presumably covering quite an area altogether, the surface was covered by gentle undulations in the form of knolls, of varying and irregular dimensions, oftentimes extensive, oftentimes a few feet only either way, with no definite arrangement of the axes. In the hollows of these, overlapping some and only coming up on the sides of others, the material subsequently to be converted into coal was laid down, and finally came the roof of sandstone, capping the whole. These irregularities have furthermore been increased by disturbances in certain parts, which have caused both rock and coal to be slickensided and rendered it extremely friable.

In the same year (1886) Lester F. Ward[75] briefly alluded to the plants from the Hayden locality known as "6 miles above Spring Canyon, near Fort Ellis, Mont.," and from several places in the Yellowstone Park. He said:

> These plants are all classed by Mr. Lesquereux in his first or lowest group as true Laramie, but upon careful investigation I am tolerably well satisfied that they belong to the Fort Union deposits.

In 1891 Walter H. Weed[76] published a short paper on "The Cinnabar and Bozeman coal fields of Montana," in which he described in some detail the coal measures of these areas. His conclusions concerning their age were set forth as follows:

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[69] U. S. Geol. Survey Terr. Fifth Ann. Rept., for 1871, pp. 1-165, 1872.

[70] Idem, pp. 296-300.

[71] U. S. Geol. Survey Terr. Sixth Ann. Rept., for 1872, pp. 108 et seq., 1873.

[72] Lesquereux, Leo, U. S. Geol. Survey Terr. Rept., vol. 7, 1878.

[73] U. S. Tenth Census, vol. 15, pp. 743-746, 1886.

[74] Idem, pp. 739-743.

[75] Synopsis of the flora of the Laramie group: U. S. Geol. Survey Sixth Ann. Rept., p. 741, 1886.

[76] Geol. Soc. America Bull., vol. 2, pp. 349-364, 1891.

> While the evidence presented in this paper is not considered conclusive, and while the work upon the district is not far enough advanced to warrant a final statement, yet it is believed that the facts show that the coal measures of the Cinnabar and Bozeman coal fields are probably of Laramie age, occurring at the very base of the Laramie series, and that they are conformably overlain by a totally different series of rocks, composed entirely of volcanic material and containing an abundant fossil flora of recognized Laramie types, in turn overlain by beds of fresh-water clays and sandstones of undetermined age but belonging to what has heretofore been considered as undoubtedly Laramie strata.

The Livingston formation was named by Weed[77] in 1893 from its typical development near the town of Livingston, Mont. For the decade or more preceding the publication of this paper the great thickness of rocks in this region above the supposed Montana Cretaceous had been very generally regarded as Laramie. Weed said:[78]

> Measured sections of the strata about the Crazy Mountains show a thickness of 12,000 feet of fresh-water sandstones and clays referred to the Laramie. It is now possible to subdivide this great thickness of beds into Laramie, a higher horizon herein named the Livingston, and the still higher beds of the Crazy Mountains, which have not as yet been differentiated into horizons but probably represent the Fort Union beds of eastern Montana.

It was thought by Weed and later by others that "these beds present proof of a series of events following the epoch of the coal-making Laramie similar to those described by Whitman Cross, in Colorado, of which the Arapahoe and the Denver beds are the evidence."

Weed's description of the Mesozoic section began with the Jurassic, above which is what he, following previous workers in the field, called the Dakota, which, he said, "forms the most persistent and readily recognizable horizon of the Rocky Mountain Mesozoic." Above the beds identified as the Dakota are over 3,000 feet of shales, in many places carbonaceous, and interbedded sandstones, that he divided about equally between the Colorado and the Montana, though he stated that "a satisfactory discrimination between the beds of the Colorado and those forming this group (Montana) can not be made on paleontologic grounds, as few fossils have been collected in the beds assigned to the Montana." The Fox Hills was not definitely recognized, though Weed said: "In the eastern part of the field the dark-gray sandy shales [of the Montana] are directly overlain by a heavy ledge of yellow, rather dark, and very massive sandstone, which is thought to be the equivalent of the Fox Hills sandstone." Conformably above this is the Laramie as then recognized. It is about 1,000 feet in thickness and is composed of massive light-colored sandstones with intercalated shale beds and coal seams. "The upper limit of the Laramie in the region studied is marked by an abrupt change in the composition of the beds and closely resembles in general characteristics that change which has been found so prominently developed in Colorado."

The Livingston was described by Weed as follows:

> Overlying the coal-bearing Laramie strata there is a series of beds constituting a newly recognized formation, for which the name Livingston is proposed, as it is typically developed in the vicinity of Livingston. This formation consists of a series of beds, in places aggregating 7,000 feet in thickness, composed of sandstones, grits, conglomerates, and clays, made up very largely of the débris of andesitic lavas and other volcanic rocks and including local intercalations of volcanic agglomerates.

The Livingston formation was believed by Weed to rest unconformably on the Laramie, and the basis for this belief was set forth at length in the paper under consideration. The upper part of the Livingston was said to pass without observed stratigraphic break into the overlying beds then presumed and since proved to belong to the Fort Union formation.

The fossil plants of the Bozeman coal field and adjacent areas were considered by me in Weed's report above cited,[79] in a more formal presentation of the facts published the preceding year.[80] The fossil flora, as then known, embraced 44 species, and the conclusion was reached that the plants from the coal-bearing beds belong "to what is generally known as the Laramie," while "the flora of the Livingston formation finds its nearest relationship with the flora of the Denver beds of Colorado."

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[77] Weed, W. H., The Laramie and the overlying Livingston formation in Montana, with report on flora, by F. H. Knowlton: U. S. Geol. Survey Bull. 105, pp. 1-68, 1893.

[78] Idem, p. 11.

[79] Knowlton, F. H., Annotated list of the fossil plants of the Bozeman, Mont., coal field, with table of distribution and description of new species: U. S. Geol. Survey Bull. 105, pp. 43-66, pls. 5, 6, 1893.

[80] Knowlton, F. H., The fossil flora of the Bozeman coal field: Washington Biol. Soc., vol. 7, pp. 153, 154, 1892.

In 1894, in the Livingston folio, Weed[81] described and mapped the several formations under discussion with the signification and limits given to them in the bulletin above cited. In 1896 the Three Forks quadrangle, which adjoins the Livingston quadrangle on the west, was described in a folio by A. C. Peale.[82] He accepted the Dakota, Colorado, Montana, Laramie, and Livingston formations as defined by Weed and wrote of the Laramie as follows:

> The formation consists essentially of light-gray or whitish sandstones, with interlaminated argillaceous beds, some of which are locally much indurated. The two areas in which the strata are best exposed are in the Nixon basin, north of the Gallatin Valley, and in the Gallatin basin, lying between the Gallatin and Madison ranges. The total thickness of the formation is from 800 to 1,000 feet. In the Nixon basin Unios and other fresh-water shells are found in connection with the coal.

Concerning the Livingston formation he said:

> The Livingston formation occupies at the present time comparatively little area within the limits of the Three Forks sheet, and nowhere is it likely that the entire thickness of the formation is shown. The largest area is probably that in the vicinity of the Sphinx Mountain, where the Sphinx conglomerate rests unconformably upon it. This area is about 15 to 20 square miles in extent, and the deposits are made up of a mass of volcanic materials indistinctly bedded, mostly andesitic in nature, and of a somber hue. At one or two places conglomerates made up of all sorts of volcanic pebbles are seen near the base. This generally black mass rests unconformably upon the eroded surfaces of the previously deposited Cretaceous formations, contrasting strongly in color with the Laramie sandstones and the Dakota conglomerates, with both of which it is in contact at different points.

The unconformable relation near Sphinx Mountain described by Peale, which was known to Weed, was one of the factors upon which Weed based his contention of an unconformity between so-called Laramie and Livingston.

Weed[83] published in 1896 a short paper which was devoted mainly to the Fort Union, with only incidental mention of the Laramie and Livingston formations. The immense section of strata forming the eastern foot slopes of the Crazy Mountains on Lebo Creek, Mont., was divided as follows: Laramie, 1,080 feet; Livingston, 7,136 feet; Fort Union, 4,649 feet.

The Little Belt Mountains quadrangle, immediately north of the Livingston quadrangle, was described by Weed[84] in 1899. The Dakota, Colorado, and Montana were grouped together in the Yellowstone formation, which was said to be followed conformably by the Laramie formation. The Laramie was described in much the same terms and assigned the same thickness as in the Livingston and Three Forks folios. The Livingston, believed to rest unconformably on the Laramie, was described at considerable length and was given a maximum thickness of 7,000 feet. In the text of the folio the Livingston was placed under the heading "Rocks of the Cretaceous period," and in the generalized section of the sedimentary rocks of the Crazy Mountains it was given as "Cretaceous?" Although included with the Livingston formation in mapping, the upper 4,000 feet of beds were in the columnar sections differentiated as the Fort Union.

The next paper in chronologic order is one by Earl Douglass,[85] published in 1902, entitled "A Cretaceous and lower Tertiary section in south-central Montana," in which the interpretation was radically different from that given by Weed. The area covered by this paper lies east of the Crazy Mountains and south of the Big Snowy Mountains, in the basin of Musselshell River. The section, according to Douglass, comprises the following units:

Tertiary.....	Fort Union.
Cretaceous..	Laramie. Fox Hills. Pierre. Fish Creek beds. Niobrara. Benton.

The Livingston formation was not recognized in this section, although the locality is only a few miles from the Lebo Creek section recorded by Weed, in which it was given a thickness of over 7,000 feet. Douglass apparently included the Livingston in whole or in major part within the so-called Laramie, concerning which he wrote as follows:

> What is supposed to be Laramie in the present section is very thick, probably approximately that of Lindgren's measurements [7,000 feet]. But here, as everywhere else, the boundaries of the Laramie are uncertain. Here,

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[81] Weed, W. H., U. S. Geol. Survey Geol. Atlas, Livingston folio (No. 1), 1894.

[82] U. S. Geol. Survey Geol. Atlas, Three Forks folio (No. 27), 1896.

[83] Weed, W. H., Am. Geologist, vol. 18, pp. 201-211, 1896.

[84] Weed, W. H., U. S. Geol. Survey Geol. Atlas, Little Belt Mountains folio (No. 56), 1899.

[85] Am. Philos. Soc. Proc., vol. 41, pp. 207-224, 1902.

> however, we have it confined between certain limits. We have it above a characteristic Fort Pierre fauna and below a characteristic Fort Union flora. Just how much of that which intervenes is Laramie is not known.

On another page he added:

> We found here no traces of the volcanic material of the Livingston formation, which only 30 or 40 miles to the southwest is so well developed.

Part of the same area was examined in 1903 by Stanton and Hatcher,[86] whose report was published in 1905. They were, however, more concerned in the elucidation of the Montana group, the classification of which, as will be subsequently shown, has played an important part in the Laramie-Livingston controversy, and they made only incidental mention of the higher beds. Concerning these they said:

> South and west of Fish Creek these shales [Bearpaw] are overlain by marine Cretaceous sandstones and by a thick series of beds that have been referred to the Laramie, Livingston, and Fort Union formations.

The generalized section for central and northern Montana as worked out by Stanton and Hatcher is as follows:

	Laramie (?).
	Fox Hills (?).
Montana group.	Bearpaw. Judith River. Claggett. Eagle.
Colorado group.	Benton.
	Dakota (?).

In 1906 R. W. Stone[87] studied the stratigraphy and coal resources of an area of approximately 1,000 square miles in central Montana, extending from Shawmut westward to the head of Musselshell River and southward in the Shields River valley to the town of Clyde Park. A large part of this belt is included in the area covered by the Little Belt Mountains folio, already mentioned, but whereas Weed recognized only four formational units in the Cretaceous system, Stone was able to differentiate and map seven such units. These were set forth by Stone as follows:

Tertiary	Fort Union formation. Livingston formation.
Cretaceous	Laramie formation. Montana group: Bearpaw shale. Judith River formation. Claggett formation. Eagle sandstone. Colorado shale. Kootenai formation.

The rocks referred to the Laramie were divided roughly into two parts. The lower division, resting on the Bearpaw shale and ranging in thickness from 200 to 460 feet, was said to be composed of red and greenish sandstones. "Its age has not been determined, but lithologically it belongs to the overlying formation and hence it will be provisionally regarded as a part of the Laramie." Concerning the upper portion, Stone said:

> Taken as a whole, the upper part of the Laramie formation is distinguished from the formations above and below by its light-gray color in comparison with their somber hues. It is composed largely of soft gray sandstone and variegated shale. The gray beds, from 1,000 to 2,400 feet thick, make a conspicuous valley. * * * The gray beds of the Laramie formation are overlain, possibly with unconformity, by somber-colored sandstone and shale which may represent the Livingston formation. Sufficient paleontologic evidence has not been obtained, however, to determine the limits of these stratigraphic units. A section measured by C. A. Fisher and T. W. Stanton on a fork of Big Elk Creek gives a thickness of 5,592 feet from the base of the Laramie to the base of the sandstone and grit probably of Fort Union age, and of 10,324 feet for the beds above the Bearpaw shale.

Douglass[88] revisited the Fish Creek area in 1909 and published additional notes on the geology, revising his previous views to some extent. He accepted the classification of the Upper Cretaceous by Stanton and Hatcher but was still more or less confused concerning the Fox Hills and the limits and extent of the so-called Laramie.

In 1909 also I published a note[89] on the geologic section of the Fish Creek area, giving it the following interpretation:

> Above the Bearpaw is a series of shaly sandstones, at least several hundred feet in thickness, that unmistakably

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[86] Stanton, T. W., and Hatcher, J. B., Geology and paleontology of the Judith River beds: U. S. Geol. Survey Bull. 257, p. 59, 1905.

[87] Coal near the Crazy Mountains, Mont.: U. S. Geol. Survey Bull. 341, pp. 78-91, 1909.

[88] Douglass, Earl, A geological reconnaissance in North Dakota, Montana, and Idaho, with notes on Mesozoic and Cenozoic geology: Carnegie Mus. Annals, vol. 5, pp. 272-280, 1909.

[89] Knowlton, F. H., The stratigraphic relations and paleontology of the "Hell Creek beds," "*Ceratops* beds," and equivalents and their reference to the Fort Union formation: Washington Acad. Sci. Proc., vol. 11, pp. 192-194, 1909.

> belong to the Livingston, as plants identical with those found near the base of this formation southeast of Bozeman, Mont., have now been located, and moreover the matrix is characteristically that of the Livingston. Between this point and the base of the upper member of the Fort Union formation, according to Stanton, is a thickness of 3,000 to 5,000 feet of beds, a portion of the lower part of which belongs with little doubt to the Livingston, but the top of the Livingston has not been definitely placed, though its maximum thickness apparently exceeds 2,000 feet. The dinosaurs occur in this thick series of beds above the Livingston, and the beds are probably referable to the lower member of the Fort Union, though no plants have been found until within approximately 1,000 feet of the top.

Later in the same year (1909) T. W. Stanton[90] published still another interpretation of the Fish Creek section. After discussing briefly the units of the Montana group and their thicknesses as worked out by Stone, he continued:

> Another important fact brought out by Stone's work is that the "Laramie" of Weed's mapping east and north of the Crazy Mountains in the Little Belt Mountains folio is really Eagle sandstone, and the "Livingston" of the same area includes in its lower part the Claggett, Judith River, and Bearpaw formations. The Livingston formation was described as resting unconformably on the Laramie and older rocks and as composed largely of andesitic material, both of which features played a prominent part in correlating the Livingston with the Denver formation. It became necessary, therefore, to study the lithologic character of the various formations of the Montana group in this area. * * * The specimens from the Eagle and a few of those from the Claggett and Judith River proved to be sandstone without admixture of igneous material, but many others from both Claggett and Judith River and some from the Bearpaw are identified as tuffaceous rock and contain much andesite.

After discussing a number of collections of invertebrates from beds originally supposed to be Laramie but here shown to be from the Claggett, Stanton said:

> With the facts above recited in mind, the whole question of the age and relations of the Livingston formation is reopened. * * * Whatever may be true of the Livingston in the type area near the town of that name, the rocks assigned to it by Weed east of the Crazy Mountains, notably in the Lebo Creek section, certainly belong to several distinct formations ranging in age from well down in the Cretaceous to the lower Eocene.

The thick series of beds referred provisionally to the Laramie by Stone and including in part at least the Fox Hills? and Laramie of Douglass were next considered. The paleontologic evidence included dinosaurs (*Triceratops* and others), fresh-water invertebrates, which "indicate close relationship with the fauna of the *Ceratops* beds of Hell Creek and Converse County," mammals, and plants.

From what has preceded it is of course evident that the previously accepted status of the Laramie and Livingston formations in the region under discussion had been brought seriously in question. The newer data bearing on the problems involved were presented in an important paper by Stone and Calvert[91] under the title "Stratigraphic relations of the Livingston formation of Montana," in which the following was given as the thesis:

> It is the purpose of this paper to show (1) that the coal-bearing formation of the Livingston section is not Laramie but is Eagle or at least lower Montana in age; (2) that the andesitic beds above, known as the Livingston formation, are not separated from the underlying formation by an unconformity anywhere within the area discussed; and (3) that their peculiar lithologic character is not a criterion of specific age but is a shore phase of many formations ranging from Colorado to Fort Union, inclusive.

Some of the main points advanced in this paper may be briefly enumerated. First, in regard to the Laramie as identified by Weed, Peale, and others, Calvert, in studying the area between Red Lodge and Livingston, observed an especially well exposed Mesozoic section on Boulder River in T. 2 S., R. 13 E., where he found invertebrates that were pronounced by Stanton to be of Colorado age at a horizon 300 feet below the lowest coal. Several similar collections were obtained on Trail Creek, near Electric, and elsewhere, from a horizon "very near the top of beds previously considered Montana," all being considered as Colorado. As this determination does not leave room for the thick Montana section between the Colorado and the "Laramie" coal measures, and moreover, as no time interval has been noted between them, the conclusion follows, according to Calvert, that the coal measures must be well down in the Montana. "At Livingston the section shows about 800 feet of coal measures, underlain by about 3,700 feet of Colorado shale, as measured below Yellowstone Canyon." This thickness of 3,700 feet accounts for the thickness assigned by Weed to both Colorado and Montana.

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[90] The age and stratigraphic relations of the "*Ceratops* beds" of Wyoming and Montana: Washington Acad. Sci. Proc., vol. 11, pp. 255-265, 1909.

[91] Stone, R. W., and Calvert, W. R., Econ. Geology, vol. 6, pp. 551-557, 652-669, 741-764, 1910.

On the east side of the Crazy Mountains Stone, starting with the Upper Cretaceous section as established on Fish Creek by Stanton and Hatcher, held that he was able to trace the heavy whitish Eagle sandstone around the north end of the mountains and thence along the eastern base of the Bridger Range to a point above Clyde Park, which was subsequently connected by Calvert, except for a number of covered areas believed by him to be unimportant, with the coal measures near Livingston. The other units of the Montana group (Claggett, Judith River, and Bearpaw) were differentiated with more or less certainty to the vicinity of Lennep, just east of the Crazy Mountains, but they disappear at the north end of the mountains and southward along the Bridger Range, the southernmost point at which either has been identified being about 10 miles north of Myersburg, or 40 miles north of Livingston, where the upper part of the Bearpaw was seen. It was argued by Stone and Calvert that south of Myersburg the Montana section interdigitates with and loses its identity in the thick Livingston beds near the type locality. Their conclusion was as follows:

> A great thickness of sedimentary deposits occurring at Livingston, Mont., composed largely of tuffaceous material, has been called the Livingston formation. It is described as lying unconformably on coal-bearing sandstone of Laramie age.
>
> The evidence, both from stratigraphy and invertebrate paleontology, submitted in these pages shows that the coal-bearing sandstone is Eagle or at least lower Montana in age. It is admitted by paleobotanists that the flora of the upper part of the coal-bearing beds is similar to the Livingston flora, the greater part of which comes from within 600 feet above the coal-bearing sandstone. The coal-bearing beds are transitional into the tuffaceous beds above. Therefore, the evidence of both stratigraphy and paleobotany indicates that the Livingston beds are conformable on the underlying coal-bearing beds.
>
> The Livingston formation was originally described as a lithologic unit of tuffaceous material derived from volcanic activity, the material of which the beds are composed and not the fossils determining the extent of the formation. Beds of this character are most abundant in the Livingston region, but they have been traced north and east around the Crazy Mountains, where beds of similar lithology are found in all the formations from Colorado to Fort Union and where they feather out into and merge with fresh and brackish water and marine deposits.
>
> Stratigraphic relations, marine invertebrates, and fossil plants prove the Montana age of the lower part of the tuffaceous beds on the west side of the Crazy Mountains originally mapped by Weed as Livingston. Northeast of the mountains some of the tuffaceous beds are younger than Bearpaw and older than Lance, while the youngest of the andesitic deposits are Fort Union. From this evidence it is concluded that the lithologic unit of tuffaceous deposits originally described as the Livingston formation has no definite age and no formational value except in the immediate vicinity of the type locality.

I dissent from the above conclusions and still hold that the Livingston, at least in the type area, is of post-Montana age.

In 1912 Calvert[92] published two short reports on the southern portion of the area including the Livingston, Trail Creek, and Electric coal fields. His conclusions are sufficiently set forth in the following generalized section:

Geologic formations in the Livingston district.

Previous interpretation.			Present interpretation.	
		Eocene.		
Post-Laramie.	Livingston, 7,000 feet.	Upper Cretaceous.	Montana.	Livingston formation, 5,000+ feet.
	Unconformity			Conformable
	Laramie, 1,000± feet.			Undifferentiated Montana, 750+ feet.
Upper Cretaceous.	Montana, 1,800 feet.			Colorado shale, 3,700 feet.
	Colorado, 1,800 feet.			
	Dakota, 500 feet.	Lower Cretaceous.		Kootenai formation, 500 feet.

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[92] Calvert, W. R., The Livingston and Trail Creek coal fields, Park, Gallatin, and Sweetgrass counties, Mont.: U. S. Geol. Survey Bull. 471, pp. 384-405, 1912; The Electric coal field, Park County, Mont.: Idem, pp. 406-422.

UINTA AND GREEN RIVER BASINS.

The Uinta and Green River basins are broad structural basins or depressions of rock strata in northwestern Colorado, southern Wyoming, and the adjacent part of Utah. The Uinta Basin, which lies south of the Uinta Mountains, extends on the east to the foothills of the Rocky Mountains and on the west to the Wasatch Mountains in Utah and is terminated on the south by the La Sal Mountains and the San Rafael Swell. It is separated from the Green River Basin by the anticlinal axis of the Uinta Mountains, which reaches eastward through Axial Basin, Colo., to the White River Plateau and the western spurs of the Rocky Mountains.

The Green River Basin was defined by Emmons [93] as follows:

> The Green River Basin proper is a rudely triangular area embraced between the systems of elevation of the Rocky Mountains on the east and the Wasatch Range on the west and extending from the sources of the Green River, in the Wind River Mountains, on the north, to the base of the Uinta Range, on the south. * * * From the western flanks of the Park Range to the outlying ridges of the Wasatch, a distance of about 150 miles, [it] extends a practically desert region.

The area as thus defined may be considered as the broader conception of the Green River Basin. It is capable of division into a number of more or less well-defined subordinate basins, such as the Red Desert Basin, the Great Divide Basin, and the Green River Basin proper.

H. S. Gale [94] in writing of these basins said:

> These two basins outline the dominant geologic structure of nearly the whole of northwestern Colorado. They are in the form of broad synclinal folds or troughs, narrowing to an apex toward the southeast. Within this State their longer axes are approximately parallel, extending from southeast to northwest. The coal-bearing rocks outcrop in practically continuous rims around the borders of the basins where they have not been buried by later formations, and the strata dip toward the interior of the basins.

These basins have been the scene of prolonged geologic research, especially in view of the bearing they have or have been supposed to have on the problems under consideration. The several fields will be taken up in sequence, so far as possible.

UINTA BASIN.

BOOK CLIFFS FIELD, UTAH AND COLORADO.

The Book Cliffs coal field forms a part of the southern rim of the Uinta Basin and extends from the vicinity of Mount Hilgard, in central Utah, northward to Castlegate and thence southward to Colorado (formerly Grand) River, in Colorado, beyond which it forms the southern face of Grand Mesa. The geology of the Book Cliffs was first studied by A. C. Peale,[95] of the Hayden Survey, who in 1876 examined the eastern part of the field. In his report the rocks now referred to the Mesaverde were separated into "Fox Hills" and "Laramie," though it was recognized that there is no lithologic break between the two, and this nomenclature was an attempt to conform to the subdivisions used in other fields.

The western part of the field was embraced in a map of the Uinta Basin by George H. Eldridge[96] published in 1901 in his report on asphalt and bituminous-rock deposits. On this map, which is of small scale, the Book Cliffs are simply denominated Cretaceous, but in the description of the formations in the Uinta Basin[97] the uppermost member of the Cretaceous, which contains the workable coals of the region, is referred to the Laramie.

The above-mentioned reports have, until recently, been practically the only source of information concerning the geology of this region, though several short papers dealing with the coal deposits were published by Hills, Storrs, Lakes, and others.

In 1905 Joseph A. Taff[98] made a careful study of the western part of the Book Cliffs field from the vicinity of Sunnyside to Castlegate, Utah, and its southern continuation along the escarpment of the Wasatch Plateau. In his report comparatively small space was devoted to the geology, which he summed up as follows:

> The rocks are naturally arranged in thick groups of strata. In each group either sandstone or shale greatly

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[93] Emmons, S. F., U. S. Geol. Expl. 40th Par. Rept., vol. 2, p. 191, 1877.

[94] U. S. Geol. Survey Bull 316, p. 270, 1907.

[95] Geological report on the Grand River district: U. S. Geol. and Geog. Survey Terr. Tenth Ann. Rept., for 1876, pp. 170-185, 1878.

[96] The asphalt and bituminous-rock deposits of the United States: U. S. Geol. Survey Twenty second Ann. Rept., pt. 1, p. 332, 1901.

[97] Idem, p. 334.

[98] Book Cliffs coal field, Utah, west of Green River: U. S. Geol. Survey Bull. 285, p. 289, 1906.

predominates. They contain scant fossil remains, and sufficient information regarding their age has not been obtained to correlate them with similar well-known beds in other parts of the country. The entire section is without doubt Cretaceous, and the principal coal-bearing strata are within the Laramie formation.

The following year (1906) the eastern part of the Book Cliffs field was studied by G. B. Richardson, and a preliminary report was issued in 1907.[99] In this report was recorded a complete change of front regarding the age of the coal-bearing rocks. Richardson said:

> Fossils have been found at several horizons between 200 feet from the base and 250 feet from the top of the formation. They consist of land plants and fresh- and brackish-water invertebrates. The evidence of the fossils and the general stratigraphic and areal relations of the beds together indicate that the coal-bearing formation should be referred to the Mesaverde rather than to the Laramie. The transition from the Mancos to the Mesaverde is marked lithologically by the increasing prevalence of sand and paleontologically by the change from marine to brackish- and fresh-water conditions. On lithologic grounds all the coal beds would be classed with the sandstone-shale formation, the greater part of which at least is considered to be Mesaverde.

Two years later (1909) Richardson's full report on this field[1] was published, and in this report the reasons for referring the coal-bearing rocks to the Mesaverde were more fully set forth:

> There has been much misapprehension concerning the age of the coal-bearing rocks of the Uinta Basin. In the Book Cliffs field, as already stated, Peale mapped the rocks here referred to the Mesaverde as two formations and correlated them respectively with the "Fox Hills" and the "Laramie." Later writers have considered the entire formation to be Laramie, because it overlies marine Cretaceous beds and in turn is overlain by Wasatch strata, and the fauna and flora were believed to belong to the Laramie.
>
> The reason for assigning the coal-bearing formation of the Book Cliffs to the Mesaverde is explained in the following extract from a letter of T. W. Stanton to the writer:
>
> "In northwestern Colorado, southern Wyoming, and elsewhere many of the coal-bearing rocks previously called Laramie are really older and are overlain by marine Cretaceous formations, thus corresponding with the Mesaverde formation first described in southwestern Colorado. * * * The invertebrate fossils that have been collected from the coal-bearing rocks of the Book Cliffs all occur in the Mesaverde of northwestern Colorado, and Dr. Knowlton finds that this is essentially true of the plants also. It is admitted that most of the fossils in question from the Book Cliffs would not seem out of place in the Laramie, yet their close agreement with those known to occur in the Mesaverde of a neighboring area and the general stratigraphic and areal relations of the rocks in which they are found make this reference to the Mesaverde most reasonable. The unconformable relations that doubtless exist between these rocks and the overlying Wasatch will explain the absence of the later Cretaceous rocks from the area."

GRAND MESA AND WEST ELK MOUNTAINS, COLORADO.

The Grand Mesa and West Elk Mountains include a very considerable area on the southern rim of the Uinta Basin, lying partly in west-central Colorado and partly in eastern Utah. The Grand Mesa field extends westward into the Book Cliffs field and eastward into the Anthracite-Crested Butte region and thence westward along the Grand Hogback, which in turn connects in part with the field in Carbon County, Wyo.

The eastern portion of this field was studied in 1874 by A. C. Peale,[2] of the Hayden Survey, before the Laramie had been established. Peale gave many sections of the rocks, especially along Grand and Gunnison rivers, and stated that in some places he had difficulty in distinguishing between Cretaceous Nos. 4 and 5, or between Pierre and Fox Hills. He said:

> The upper portion of these beds may possibly have to be referred to the Lignitic group, but for the present I refer them to the Upper Cretaceous.

On the publication of the Geological Atlas of the Hayden Survey, in 1881, the coal-bearing rocks of this region were referred to the Laramie, which had then become very generally accepted, and this reference was followed in the main by geologists who had occasion to discuss the area. Thus in 1894 George H. Eldridge, in the Anthracite-Crested Butte folio,[3] gave a section which, at least from the base of the Fox Hills, corresponds in part with that of the Hayden Survey Atlas. The coal-bearing beds were referred to as the "Laramie coal measures" and were said to have a maximum thickness of 2,000 feet; they were described as being overlain unconformably by the Tertiary Ohio formation.

In 1907 W. T. Lee[4] investigated the Grand Mesa coal field and obtained information which made it necessary to modify greatly the determination of the age relations of the principal coal-bearing portion of the section, until then accepted as Laramie. It was referred to the Mesaverde formation and was described by Lee as follows:

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[99] Richardson, G. B., The Book Cliffs coal field, between Grand River, Colo., and Sunnyside, Utah: U. S. Geol. Survey Bull. 316, pp. 302-320, 1907.

[1] Richardson, G. B., Reconnaissance of the Book Cliffs coal field between Grand River, Colo., and Sunnyside, Utah: U. S. Geol. Survey Bull. 371, 1909.

[2] U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1874, pp. 73-179, 1876.

[3] U. S. Geol. Survey Geol. Atlas, Folio 9, 1894.

[4] Lee, W. T., The Grand Mesa coal field, Colo.: U. S. Geol. Survey Bull. 341, p. 306, 1909.

> The lower part of it [Mesaverde] was called "Fox Hills" and the upper part "Laramie" by the geologists of the Hayden Survey, and other geologists have followed them in referring the coal to the Laramie. However, a study of the fossils, in connection with the stratigraphy of western Colorado, proves that it is much older than the Laramie, and the entire series of coal-bearing rocks in this field is now referred to the Mesaverde formation, originally named by Holmes in southwestern Colorado. Where the full section is exposed the Mesaverde is separated from the Laramie by a marine formation known as the Lewis shale, but in the Grand Mesa field there is no representative of the Lewis or Laramie beds. The sedimentary rocks of Tertiary age rest unconformably upon the Mesaverde.

Lee[5] continued and extended the work in this field in 1909. On further and more critical study it was found possible to separate the Mesaverde into several members, as follows: The Rollins sandstone member, at the base, is a white cliff-making sandstone containing fucoids and marine invertebrates. Above this is the Bowie shale member, with a maximum thickness of about 425 feet, composed of dark-colored shale and gray sandstone. It contains marine and brackish-water invertebrates and important coal deposits; it is not present in all parts of the field. Unconformably above this is the Paonia shale member, 400 feet thick, made up of sandstone and shale, in places carbonaceous, with plant remains, mainly fresh-water invertebrates and coal deposits. Above the Paonia is what is called the undifferentiated part of the Mesaverde, a series of gray quartzose sandstones and shales some 2,000 feet thick, containing plants and fresh-water invertebrates.

The Paonia shale member and the overlying undifferentiated Mesaverde constitute the beds which had previously been called Laramie and which, according to Lee, "may prove to be Laramie or younger." The age significance of the invertebrates from these beds was interpreted by Stanton as follows:

> Although this nonmarine fauna contains many Laramie elements, on the whole it agrees better with the fauna of the Mesaverde as we are now beginning to know it, and the stratigraphic and structural evidence of the entire region, including the Durango, Grand Hogback, and Yampa fields, is strongly in favor of referring all the upper coal-bearing beds of the Grand Mesa field to the Mesaverde.

The plants were critically reviewed by me as follows:

> In conclusion I feel justified in stating that in my opinion the beds containing the plants here under discussion are of post-Montana age. The facts upon which this conclusion is based are (1) the apparently satisfactory demonstration of an unconformity between the upper and lower coal-bearing rocks, (2) the fact that the marine invertebrates are confined to the beds below the unconformity, (3) the fact that the plants are confined to the beds above the unconformity, (4) the marked difference in the quality of the coals in the lower and upper beds—that is, below and above the unconformity, (5) the marked resemblance between the plants of the Grand Mesa field and those of Black Buttes, Wyo., which is only a short distance north, and (6) when the first report was given, comparisons of the plants were made with areas then tentatively regarded as Montana but which subsequent investigation has shown beyond much question to be of post-Montana age.

From the above exposition it appears that the upper coal-bearing beds in the Grand Mesa region that were formerly regarded as of Laramie age are now tentatively classed as Mesaverde, with the possibility that subsequent study may prove that they are Laramie or younger. In any event, their reference to the Laramie is not now accepted.

GLENWOOD SPRINGS AREA, COLORADO.

The Glenwood Springs area is directly north of the Grand Mesa area and is in stratigraphic connection with it. It has been studied by A. L. Beekly, of the United States Geological Survey, but the report is not yet published. A brief description of this field was given by Gale,[6] who showed that it also merges with the Grand Hogback field and has the same structural relations. The section of coal-bearing rocks is essentially the same as that of Grand Mesa and like it was referred to the Mesaverde, and both Lewis and Laramie were believed to be absent. In considering the paleobotanic evidence for the possible "Laramie or later" age of the beds in the Grand Mesa area above the Paonia shale, I wrote as follows[7] concerning similar evidence in the Glenwood Springs field:

> If the discussions and comparisons made above had included the adjacent Glenwood Springs area, with which

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[5] Lee, W. T., Coal fields of Grand Mesa and the West Elk Mountains, Colo.: U. S. Geol. Survey Bull. 510, 1912.

[6] Gale, H. S., Coal fields of northwestern Colorado and northeastern Utah: U. S. Geol. Survey Bull. 415, pp. 128-136, 1910.

[7] Knowlton, F. H., in Lee, W. T., Coal fields of Grand Mesa and the West Elk Mountains, Colo.: U. S. Geol. Survey Bull. 510, p. 47, 1912.

there is stratigraphic connection, the post-Montana facies would be even more apparent. In the latter area are found such distinctively post-Montana forms as *Zizyphus fibrillosus*, *Cinnamomum affine*, *Populus meekii?*, *Populus monodon*, *Viburnum contortum*, etc., which have not been noted in the Grand Mesa field. This but emphasizes the fact that the collections of plants are too meager and obviously incomplete to enable us to reach thoroughly conclusive results, though when fuller collections are obtained, as in the Glenwood Springs area, the resemblance to higher beds is accentuated.

GRAND HOGBACK AND DANFORTH HILLS AREA, COLORADO.

The important coal area of the Grand Hogback and Danforth Hills lies along the eastern rim of the Uinta Basin and is in direct stratigraphic connection with the Glenwood Springs area, on the southeast, while to the west it passes with some interruptions into the less important coal field of Uinta County, Utah. This general region was visited in 1872 by S. F. Emmons,[8] of the Fortieth Parallel Survey, and in 1876 and 1877 by C. A. White,[9] of the Hayden Survey. White referred the coal-bearing rocks of this region to the Fox Hills and Laramie. The Fox Hills, in accordance with what he called the "modified classification of the Cretaceous strata adopted in this report," included both the Pierre and Fox Hills of the Missouri River section and was regarded as of Cretaceous age, while the Laramie was classed as post-Cretaceous and was supposed to be transitional between Cretaceous and Tertiary.

A number of other reports on the coal resources of the region by Chisholm, Hills, Storrs, Hewett, and others do not need special mention in this connection.

This field was studied by H. S. Gale[10] in 1906, and the final results in this and other related areas in northwestern Colorado and northeastern Utah were published in 1910.[11] The section as worked out by Gale is essentially the same as that in the Book Cliffs, Grand Mesa, and Glenwood Springs fields—that is, the Mesaverde formation was regarded as the uppermost or youngest formation of the Upper Cretaceous section in this part of the basin. The divisions established by Lee in the Grand Mesa region were not recognized by Gale, though he divided the Mesaverde into lower and upper members, the line of separation being in many parts of the field a conspicuous white sandstone. The character of the two members was described as follows:

> Fossil invertebrates have been found in almost all parts of the Mesaverde formation. They indicate that the lower part is largely of marine origin, up to and probably including the "white rock." Above the "white rock" fresh and brackish water invertebrates and plants indicate a change of character in the body of water in which the succeeding beds were formed. The fresh or brackish water conditions, however, were not permanent and gave way to true marine conditions again near the top of the formation.

The absence of the Lewis shale and the "Laramie," both of which are present in the adjacent Yampa field, may of course be explained in either of two ways—that is, they may never have been deposited in this basin, or, if deposited, they may have been removed by erosion. The fossil plants, so far as they have been discussed in published reports, appear to be of Mesaverde types, but there is some evidence not yet published that suggests the possibility that the Laramie also may be represented here. Be this as it may, however, the Laramie is not now recognized as present in the Grand Hogback and Danforth Hills fields, or, indeed, in the Uinta Basin.

The conditions just described may be traced westward from the Danforth Hills, except that the unconformity separating the Mesaverde from the overlying Tertiary appears to cut deeper and deeper. Thus at Vernal, Utah, the Mesaverde is only about 1,500 feet thick, and the upper coal-bearing portion is thought to be absent, and in the Deep Creek district in Uinta County, Utah, the whole of the Mesaverde has apparently been removed. Reports on several of these fields have been made by Gale,[12] Lupton,[13] and others, but as the Laramie is not involved, they may be passed over.

GREEN RIVER BASIN.

YAMPA COAL FIELD, COLORADO.

The Yampa field, which occupies a considerable area in Routt County, Colo., lies along the southern border of the Green River Basin and is separated from the Uinta Basin by an anticlinal axis that extends from the Uinta Mountains eastward to the Rocky Mountains. At one point in Axial Basin only about 4 miles intervenes between the Yampa and Danforth Hills fields, yet the sections of coal-bearing rocks in the two areas, as published, are considerably different.

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[8] U. S. Geol. Expl. 40th Par. Rept., vol. 2, pp. 167–189, 1877.

[9] U. S. Geol. and Geog. Survey Terr. Tenth Ann. Rept., for 1876, pp. 5–60, 1878.

[10] Coal fields of the Danforth Hills and Grand Hogback, in northwestern Colorado: U. S. Geol. Survey Bull. 316, 1906, p. 264, 1907.

[11] Coal fields of northwestern Colorado and northeastern Utah: U. S. Survey Bull. 415, 1910.

[12] Gale, H. S., Coal fields of northwestern Colorado and northeastern Utah: U. S. Geol. Survey Bull. 415, pp. 179–219, 1910; Geology of the Rangely oil district, Rio Blanco County, Colo.: U. S. Geol. Survey Bull. 350, 1908.

[13] Lupton, C. T., The Deep Creek district of the Vernal coal field, Uinta County, Utah: U. S. Geol. Survey Bull. 471, p. 579, 1912; The Blacktail (Tabby) Mountain coal field, Wasatch County, Utah: Idem, p. 595.

The Yampa field was studied by members of both the King and Hayden surveys, and the coal-bearing rocks were in large part referred to the Laramie, a reference that became more and more firmly fixed as time went on; in fact, the whole coal-bearing section was accepted as of this age until about 1905. In that year this field was investigated by Fenneman and Gale,[14] who were able to divide the Cretaceous portion of the coal-bearing rocks into three formations—the Mesaverde, which was believed to correspond in whole or in part to the beds so named in southwestern Colorado; the Lewis shale, a marine formation of soft shales and sandstones overlying the Mesaverde; and the Laramie. This field, together with the others to the south, was more fully considered by Gale [15] in 1910.

The "Laramie" in the Yampa field was described as being about 1,200 feet thick and composed of relatively soft sandstones and shales. It was said to be limited at the top by an unconformity that separates it from overlying Tertiary beds, also coal-bearing, which are probably to be regarded as Fort Union or its equivalent. The base of the "Laramie"—that is, the line separating it from the Lewis—was apparently established with difficulty; in fact, it appears to have been drawn arbitrarily in this field. On this point Gale said:

> As mapped, the formation is intended to represent a group that is distinguished from those adjacent by a difference of rock composition and that may be recognized by this distinction in the field. In the case of the Laramie the feature that distinguishes it from the underlying Lewis shale is the presence of sandstone beds that form prominent ridges or ledges in the topography. Unfortunately the horizon of its lowest sandstone does not appear to be constant in different parts of the field, so that if it were possible to fix on a single definite plane as marking the basal member of that formation and trace it throughout the field, it would not everywhere lie in the same relation to the lowest of the principal group of sandstones overlying. Furthermore, though the formation as a whole is considered to mark the transition from marine to brackish and fresh water deposits, the fossils found in the lowest part of the sandstones included in the Laramie, including those in the massive sandstone beds, are distinctly marine and include a fauna apparently not distinguishable from that of the Lewis beneath.

North of Craig the relations at the base of the "Laramie" appear to be particularly uncertain. Gale stated:

> The base of the Laramie formation has been assumed to be at the base of the ledge that forms the prominent cliff or rock wall just north of the town. The outcrop of this stratum may be traced almost continuously for about 6 miles west of Craig, but beyond that it is concealed by the overlapping deposits of the Browns Park formation. Similar beds are again revealed farther west. * * * In that region the identity of the horizon already adopted as marking the base of the Laramie is, however, much in doubt.

LITTLE SNAKE RIVER AREA, WYOMING AND COLORADO

The area drained by Little Snake River extends from the Sierra Madre westward to the Red Desert, and from the summit of the Elkhead Mountains in Colorado northward to the divide separating this area from the Great Divide Basin, which is just south of the Union Pacific Railroad. It is separated by the Elkhead Mountains from the Yampa field, considered above.

The western part of this field was studied by M. W. Ball [16] in 1907, and the eastern part by Ball and Stebinger [17] in 1908. The section is essentially the same as that of the Yampa field and also of the field studied by A. C. Veatch in east-central Carbon County. As these areas will be considered in detail in discussing the relations between the Laramie of the Denver Basin and the so-called "Lower Laramie" of Veatch, no further mention at this point is necessary.

CARBON COUNTY, WYOMING, AND ADJACENT AREAS.

An extensive area lying mainly in east-central Carbon County, Wyo., just east of the Green River Basin and forming the western part of what has sometimes been designated the Laramie Plains, is a structural and geologic basin lying in the angle where the Rocky Mountains, from their west of south course through Colorado, turn northwestward through Wyoming toward the Yellowstone National Park. With this area is also considered a long, narrow area extending southward from the vicinity of Rawlins, Wyo., into Routt County, Colo., and connecting through the Elkhead Mountains with the Yampa coal field, which is separated only by the Axial Basin from the coal-bearing rocks that more or less completely surround the Uinta Basin.

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[14] Fenneman, N. M., and Gale, H. S., The Yampa coal field, Routt County, Colo.: U. S. Geol. Survey Bull. 297, 1906.

[15] Gale, H. S., Coal fields of northwestern Colorado and northeastern Utah: U. S. Geol. Survey Bull. 415, 1910.

[16] Ball, M. W., The western part of the Little Snake River coal field, Wyo.: U. S. Geol. Survey Bull. 341, p. 243, 1909.

[17] Ball, M. W., and Stebinger, Eugene, The eastern part of the Little Snake River coal field, Wyo.: U. S. Geol. Survey Bull. 381, p. 186, 1910.

East-central Carbon County has been the scene of more or less critical geologic study for nearly 50 years. The historical account of this work is presented in detail on pages 61-65 and need not be repeated here, except in so far as is necessary to keep the problem well in mind. The following is the section of the rocks of the region as worked out by Veatch:[18]

	Feet.
North Park Tertiary	4,500
Unconformity.	
Fort Union	800-2,000
"Upper Laramie"	6,000
Unconformity.	
"Lower Laramie"	6,500
Montana:	
Lewis } Fox Hills of the early surveys.	3,000
Mesaverde. } Fox Hills of the early surveys.	3,200
"Pierre shale"	3,500
Colorado:	
Niobrara	800
Benton	1,500
Dakota	150
Morrison	200
Marine Jurassic	75
Red beds	1,650
Carboniferous	1,800
Pre-Cambrian crystallines.	

The section of coal-bearing rocks, given a thickness of 12,500 feet by Veatch, was supposed, prior to his work in 1906, to be a unit and all referable to the Laramie. Veatch's discovery of a profound unconformity, then thought to be similar in position and magnitude to that detected by Cross in the Denver Basin, naturally made a readjustment necessary, and consequently the beds above the unconformity were called the "Upper Laramie" and those below it the "Lower Laramie." The latter therefore corresponds in position to the Laramie of the Denver Basin, and the present comparison is instituted to ascertain the bearing of the floras on this correlation.

Fossil plants occur in greater or less abundance in connection with the coal, especially in the vicinity of Carbon, where some of the earliest mines were situated, but it now appears that the work of the Hayden and King surveys was all along or south of the Union Pacific Railroad, where the lower division is usually absent, hence the plants studied by Lesquereux were from the "Upper Laramie," and it is now plain why the "Laramie" of this region appeared to be so distinctively Tertiary in facies. Since the importance of having collections from the "Lower Laramie" has become realized plants have been procured from many localities, as is shown by the lists on page 100, where further data on the geologic occurrence are given.

It was evident that much more field work would be necessary in this region before several more or less discordant views could be harmonized. This was finally accomplished by Bowen, and his results were published in 1918 in a paper entitled "Stratigraphy of the Hanna Basin, Wyo."[19] In this paper Bowen made a number of important changes in the interpretation of the Carbon County section as given by Veatch. The two sections are given below:

Section in Carbon County, Wyo.

	Bowen, 1918.	Veatch, 1912.
Tertiary.	North Park formation 0-400 feet.	North Park Tertiary, 4,500 feet.
	Unconformity	Unconformity
	Hanna formation, 7,000± feet.	Fort Union formation, 800-2,000 feet.
	Unconformity	
Tertiary (?).	Ferris formation, 6,500± feet.	"Upper Laramie," 6,000 feet.
		Unconformity
Cretaceous.	Medicine Bow formation, 6,200± feet.	"Lower Laramie," 6,500 feet.
	Lewis shale.	Lewis shale.

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[18] Veatch, A. C., On the origin and definition of the geologic term "Laramie": Jour. Geology, vol. 15, p. 527, 1907.

[19] Bowen, C. F., U. S. Geol. Survey Prof. Paper 108, pp. 227-235, 1918.

Bowen wrote as follows concerning this section:

> Above the highest marine formation—the Lewis shale—is a mass of continental deposits, divisible into four formations having a maximum thickness of more than 20,000 feet. For the lowest of these formations the name Medicine Bow is here proposed, because the formation is best exposed and most easily studied along both sides of North Platte River at the mouth of the Medicine Bow. The Medicine Bow formation is the equivalent of the "Lower Laramie" as defined by Veatch. The latter term is not applicable, for the "Upper Laramie," in the sense in which that term was originally used, is not of Laramie age. As the relation of the Medicine Bow formation to the Laramie of the Denver Basin can not be determined by field relations, and as paleontologists are not agreed as to the relation of the fossil remains found in the two formations, the use of the unqualified term "Laramie" is not advisable, and it is thought that confusion may be avoided by the use of an entirely new name for the formation hitherto called "Lower Laramie."
>
> The Medicine Bow formation rests conformably on the Lewis shale and consists of an alternating succession of shale and massive to thin-bedded, ripple-marked, and cross-bedded sandstones, with several beds of coal in the lower third of the formation. * * *
>
> The Medicine Bow formation is terminated above by a conglomeratic zone taken as the base of the Ferris formation, so named because it is best exposed at the old Ferris ranch, on North Platte River. * * * As defined the Ferris formation is approximately equivalent to the lower half of the "Upper Laramie" of Veatch. The conglomerate at the base of the Ferris formation ranges through an interval of about 1,000 feet, in which massive sandstone, more or less conglomeratic, alternates with nonconglomeratic sandstone and shale. * * * For the upper part of the "Upper Laramie" as defined by Veatch the name Hanna formation is proposed, because the formation is well exposed to the west and north of the town of Hanna and yields all the coal mined at that place.

According to Bowen, perhaps the most interesting structural problem in the field relates to the occurrence and magnitude of the unconformities. He said:

> There are certainly two and possibly three unconformities present. The highest of these is at the base of the North Park formation, which overlaps all other formations in the field.
>
> The next lower unconformity is that at the base of the Hanna formation, formerly assigned to the base of the Ferris formation. It represents the removal of more rather than less than the 20,000 feet assigned by Veatch.

This was thought by Bowen to be the unconformity assigned by Veatch to the base of his "Upper Laramie." Veatch's mistake was perhaps natural, as it resulted from rapid reconnaissance work.

The possibility of a third unconformity—namely, at the base of the Ferris formation—was discussed at length by Bowen, who showed that there is a well-marked conglomerate at the base of the Ferris formation and in seeking to interpret its significance commented as follows:

> The field relations of the Ferris conglomerate and the underlying formation show (1) that the two have been equally deformed; (2) that there is no angular discordance between them either in the Hanna Basin or in other areas where both are present; (3) that the Ferris formation is nowhere known to transgress the Medicine Bow formation and overlap older rocks; (4) that, as previously indicated, the conglomerate seems to have been derived from the same source as the Medicine Bow; (5) that there appears to be a gradual transition from the Medicine Bow formation to the Ferris formation.

Bowen therefore concluded

> that the weight of evidence so far as it can now be interpreted is opposed to the existence of a great unconformity at the base of the Ferris formation, but it is freely admitted that more detailed field work over wider areas is necessary to decide this question.

As regards the paleontologic evidence afforded by what is now called the Medicine Bow formation Bowen wrote as follows:

> The plants are regarded by F. H. Knowlton as of the same age as the plants of the Laramie of the Denver Basin. The invertebrates are considered by T. W. Stanton as belonging to the fauna of the Lance formation. The bones belong in part to the ceratopsians, but no specimens have been found that are sufficiently diagnostic for even generic determination.

BLACK BUTTES, WYOMING.

Hardly any other locality that is involved in the Laramie problem has given rise to more extended discussions than Black Buttes, Wyo. Being on the line of the first completed transcontinental railway, it was early made easily accessible and, moreover, it happened to fall within the areas studied by three of the geological survey organizations that worked in the West 40 years or more ago, with the result that it has been discussed and described more frequently and by a greater number of students than any other similar area that has been referred to the Laramie. The first dinosaur (*Agathaumas sylvestris*) accredited to the Laramie, which was supposed to fix the Cretaceous age of everything associated with it, was found at Black Buttes. This locality has also afforded large collections of fossil plants and "a greater number of the described invertebrate species of the Laramie than any other single locality."

As much of the early history of opinion regarding Black Buttes has been given on pages 8–9, it is only necessary to refer to it in the briefest manner at this point. As is well known, Lesquereux from his studies of the fossil plants argued strenuously for the Tertiary age of the coal and plant bearing beds at Black Buttes. Hayden also regarded these beds as Tertiary, or, after the establishment of the Laramie, as in a measure transitional between Cretaceous and Tertiary. In 1872 Meek and Bannister visited this region and discovered the remains of the dinosaur which has played so prominent a part in the discussion of the age of these beds. These dinosaurian remains were described the same year by Cope, who of course referred the beds containing them without hesitation to the Cretaceous, as he and other vertebrate paleontologists considered the mere presence of dinosaurs as proof positive of Cretaceous age. Meek, in discussing the age of the deposits at Black Buttes ("Bitter Creek beds" of Powell), was extremely cautious, his statement being as follows:

> As we discovered in these rocks between three and four times as many species of fossils as had been previously known from the same, it becomes a matter of some interest to consider the whole with regard to their bearing on the question as to the age of the group. The reptilian remains found at Black Butte, near the top of the series, have, as elsewhere stated, been investigated by Prof. Cope and by him pronounced to be decidedly dinosaurian and therefore indicative of Cretaceous age; on the other hand, the fossil plants from the same beds have been studied by Prof. Lesquereux, who informs me that they are unquestionable Tertiary types. My own investigations having been confined to the invertebrates, it is of these chiefly that I will speak here. In the first place, it will be seen that all of these yet known belong to a few genera of mollusks, represented by some twelve or fourteen species. And just here it may be stated that, although partly committed in favor of the opinion that this formation belongs to the Cretaceous and still provisionally viewing it as most probably such, I do not wish to disguise or conceal the fact that the evidence favoring this conclusion, to be derived from the mollusks alone, as now known, is by no means strong or convincing. The genera are probably all common both to the Cretaceous and Tertiary as well as to the present epoch.

Meek finally concluded that "aside from the dinosaurian, the organic remains favor the conclusion that it is Tertiary." Later, however (1876), he recorded his impression that the "Bitter Creek series" and the underlying "Point of Rocks series" should probably be considered a unit and hence were presumably Cretaceous, though again he was far from positive in his opinion.

In 1876 J. W. Powell published his "Report on the geology of the eastern portion of the Uinta Mountains," which contains also a chapter on the paleontology by C. A. White. In this report the "Bitter Creek group" was placed unqualifiedly in the Tertiary and was described as resting with marked angular unconformity on the underlying "Point of Rocks group." In commenting on this King [20] wrote as follows:

> Powell and White draw the line below the Hallville and Black Butte coals, leaving these upper beds, including the dinosaurian and leaf beds of Black Butte, in the Tertiary. They describe a slight "nonconformity of erosion," producing little irregularities in the upper surface of the bed directly above the horizon of the *Anomia* and *Odontobasis* in the lower strata near Point of Rocks. This, however, draws an arbitrary line between the groups of fossils of close relationship, some of the identical forms occurring in their upper Cretaceous appearing in their lower Tertiary at Black Butte. Moreover, they disregard entirely the evidence of the dinosaurian, which would seem to be conclusive proof of Cretaceous age. We prefer to draw the line at the top of Black Butte, including the dinosaurian and plant beds in the Cretaceous, believing also that in tracing the contact between the beds next over the dinosaurian series and the ashy beds which overlie them we detect a slight unconformity, which, when traced north, seems both more persistent and more observable than the unconformity of erosion noted by Powell, which we fail to follow north.

Later (1877) White placed the beds at Black Buttes in the Laramie, which he then regarded as of post-Cretaceous age, though ultimately he of course came to consider it as Cretaceous. In 1886 Lester F. Ward published his "Synopsis of the flora of the Laramie group," in which the plant beds at Black Buttes were discussed and a few plants were described. He was not able to decide from the data he employed whether the Laramie is Cretaceous or Tertiary, though he inclined to the then prevailing opinion that it is Cretaceous.

In 1896 T. W. Stanton and I [21] spent several days in studying the section at Black Buttes and in collecting plants and invertebrates. We did not succeed in finding any trace of vertebrate remains, though the horizon that had afforded the celebrated *Agathaumas* was at least approximately placed and the beds carefully searched. The conclusion was reached that the beds here under consideration rest conformably on the underlying Cretaceous and pass upward without observed discordance into beds then identified as Fort Union and Wasatch. They seemed to fill all the requirements demanded by the definition of the Laramie and were so referred.

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[20] King, Clarence, Systematic geology: U. S. Geol. Expl. 40th Par. Rept., vol. 1, p. 338, 1878.

[21] Stanton, T. W., and Knowlton, F. H., Stratigraphy and paleontology of the Laramie and related formations in Wyoming: Geol. Soc. America Bull., vol. 8, pp. 127-156, 1907.

For a number of years after the publication of the above-mentioned paper there was little activity in the study of the Black Buttes region. In 1907 A. R. Schultz [22] and party made an investigation of the coal resources of the northern part of the Rock Springs coal field and reached important conclusions concerning the geology of this and adjacent areas. The oldest rocks exposed in the region were identified as of Montana age, and names were applied to them that had been established in southern Colorado. The lowest, called the Mesaverde formation, is made up of four members and aggregates 5,000 feet in thickness. Conformably above the Mesaverde is the Lewis shale, composed of soft gray, drab, and black gypsiferous shale and soft shaly sandstones and forming a region of low relief. The lower part of the Mesaverde was said to include in the main the "Point of Rocks series" of Powell, and the upper part of the Mesaverde and the Lewis shale Schultz assigned to the "Bitter Creek." Above the Lewis shale and apparently conformable with it is the so-called Black Buttes coal group, which was described by Schultz, as follows:

> Along the east side of the [Rock Springs] dome the Black Buttes coal group lies conformably upon marine Lewis shale, which weathers readily and produces regions of low relief. The basal member of the Black Buttes coal group consists of a massive bed of yellowish-white sandstone, in places over 100 feet thick and not known to be coal bearing. This member, resting upon the soft, friable Lewis shale, forms steep hills and cliffs along the contact. The rocks above the sandstone consist of a series of variable sandstones, clay, and coal beds that lie exposed in the low hills and ridges east of the main scarp. On the west side of the dome this group is absent.

In the tabular statement the Black Buttes coal group was referred to as Laramie (?). Its maximum thickness in this field was given as 2,371 feet. Resting unconformably on the Black Buttes coal group is the Black Rock coal group, which in the table was classed as Wasatch, although in the discussion Schultz stated that it "is thought to belong to the Fort Union formation." In thickness it ranges from 1,200 to over 2,600 feet. The Black Rock coal group was briefly described by Schultz as follows:

> At the base is a thin band of conglomerate, ranging in thickness from 2 to 6 feet. The pebbles are very fine, consisting mostly of quartz, although in many places other pebbles are present. This conglomerate marks an unconformable contact between this coal group and the Black Buttes. Lithologically this group resembles the upper part of the Black Buttes coal group. The sandstone and shale, however, are more highly colored and more poorly cemented and contain a large number of spherical and irregular concretions. The formation is prolifically coal bearing.

In the following season (1908) Schultz [23] investigated the southern part of the Rock Springs coal field, which included the Black Buttes area, though Black Buttes is really on the line between the two areas. The section up to and including the Black Buttes coal group was found to be the same as that just described for the northern part of the Rock Springs dome, but above this point in the general section of the whole region a number of differences were discovered. Although not then known to be anywhere exposed in the Rock Springs dome, it appeared from studies in the Rawlins area, to the east, that there is an immense series of soft sandstones and shales, called the Knobs-Cherokee coal group, with a thickness of 6,000 to 9,400 feet, which is to be intercalated between the Black Buttes and Black Rock coal groups. If these thicknesses are even approximately correct, as they are believed to be, the unconformity between these two series of beds is of course one of tremendous magnitude. As regards the age determinations, the Knobs-Cherokee coal group was referred by Schultz to the "Upper Laramie" of Veatch as defined in Carbon County, Wyo., while the Black Rock coal group was still referred to the Wasatch, although containing a Fort Union flora.

The general geologic relations of the Black Buttes area having been discussed, a more detailed description of the beds in question may now be given. The following is quoted from the paper by Stanto and Knowlton already mentioned:

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[22] U. S. Geol. Survey Bull, 341, pp. 256-282, 1909.

[23] U. S. Geol. Survey Bull. 381, p. 214, 1910.

> The most prominent feature of the section at Black Buttes is the massive bed of sandstone, somewhat over 100 feet thick at the base of the exposure, forming steep hills and cliffs northeast of the railroad opposite the station and passing beneath the surface by its dip of 9° or 10° near the coal mine. The upper portion of it is also exposed on the south side of Bitter Creek valley, about a mile from the station. All of the Laramie fossils, whether plants, invertebrates, or vertebrates, that have hitherto been described or listed as coming from Black Buttes were obtained from the overlying beds within about 100 feet of the top of this massive sandstone. The original specimen of *Agathaumas sylvestris* was found about 20 feet above it, and the plants that have been described came from the same horizon and from several higher bands up to the bed overlying the principal coal, some 60 or 75 feet higher. The invertebrates from this locality have about the same range. Most of the beds vary considerably in character and thickness within short distances; but the fossiliferous and overlying portions of the section may be described in general terms as a series of variable sandstones, clays, and coal beds exposed in low hills and ridges with a dip of 9° or 10° eastward at the base, but decreasing in the upper portions to 5° or 6°, which is about the same as the overlying Wasatch beds.
>
> The character of the mollusks shows that the lower beds were mostly deposited in brackish waters, but that there were alternations of fresh waters in which the genus *Unio* thrived with an abundance of individuals and great variety of species, and several fresh-water gastropods were common. Between the top of the massive sandstone and the dinosaur horizon there is a band filled with brackish-water fossils, including *Ostrea glabra* var. *arcuatilis* Meek, *Anomia micronema* Meek, *Corbula undifera* Meek, and *Modiola* sp. The greater number of the Black Buttes invertebrates, however, have been obtained from strata some 40 or 50 feet higher and consequently a little above the dinosaur bed. Here there is a band which in some places is about 4 feet thick, almost wholly made up of shells. By far the most abundant species is *Corbicula fracta* Meek, and immediately associated with it are *Corbicula occidentalis* Meek and Hayden, *Neritina baptista* White, *N. valvilineata* White, and *Melania wyomingensis* Meek, all of which probably lived in slightly brackish water, for this species of *Melania* has almost invariably been found associated with brackish-water or marine forms, although it belongs to a fresh-water genus. At the base of this shell bed and immediately above a coal seam *Unio* shells are abundant. These purely fresh-water forms are found on the slope mingled with the *Corbicula* shells, but all that were found in situ were either at the base of or a few feet above the *Corbicula* bed.

We may now consider the delimitation of the base of the beds at Black Buttes (=Laramie of White and many subsequent writers, Black Buttes coal group of Schultz, etc.) in the light of certain recently acquired but hitherto unpublished data. Powell described the "Bitter Creek series" as resting with marked unconformity on the underlying "Point of Rocks series." Meek was inclined to draw the line at the point—if it could be determined—where the fresh-water deposits begin and the estuarine or brackish-water deposits cease, "considering the brackish-water deposits most probably Cretaceous, and those above them Tertiary." Bannister described an apparent unconformity beneath 130 feet of "thin sandstone alternating with grayish shaly clays," which underlie the massive sandstone that forms bluffs

> on the northern edge of the bottom lands of Bitter Creek for a distance of 2 or 3 miles northwest of Black Buttes station, where there appears below them, and apparently dipping unconformably beneath them, a massive bluish-white soft sandstone. * * * The dip of the underlying beds is nearly southeast about 18°, while that of the overlying rocks is only from 5° to 7° and nearly due east.

King detected "a slight unconformity between the beds next over the dinosaurian series and the ashy beds which overlie them," which had the effect of placing the *Agathaumas* in the Cretaceous. None of these supposed unconformities, however, appear to have been definitely detected and accepted by subsequent students.

In later years it came to be the prevailing custom to make the massive sandstone so conspicuous at the base of the exposure the basal portion of the so-called "Laramie" section at Black Buttes, because sedimentation was supposed to be uninterrupted between this massive sandstone and the overlying beds, and, moreover, because the sandstone is very sharply delimited from the underlying soft Lewis shale.

In 1909 A. C. Peale and I spent several weeks in the study of the section at Black Buttes and vicinity. In the massive sandstones a few hundred yards northeast of the station we found numerous specimens of *Halymenites major* Lesquereux, an alga, which wide experience has shown is present only in marine beds. In addition to this, we found a number of invertebrates which, although fragmentary, were, in the opinion of T. W. Stanton, sufficient to prove that the beds are marine and probably of Fox Hills age. We also observed what we interpreted as an unconformity between this massive sandstone and the overlying soft shales containing the fauna and flora under consideration. In the vicinity of the station at Black

Buttes and for many miles southwest of the railroad the uppermost layer of this basal sandstone is a soft white sandstone which can be easily traced. It has a maximum thickness of 20 feet, but the thickness varies from point to point, in some place being reduced to a foot or less, and in one locality about 2 miles south of the railroad the white sandstone has entirely disappeared and the soft shales rest on the yellowish sandstone. At another point about 8 miles southeast of the railroad we observed an irregular trench at least 10 feet deep in this white sandstone, which was filled almost solid with the shells of *Corbicula fracta*, a well-known species of the upper beds.

It is but fair to state, however, that the above interpretation of observed conditions has not been accepted by Schultz and other observers, who argue that although the upper white sandstone may vary in thickness from place to place the variation is due to a lateral change in color from white to brown, and vice versa, rather than to erosion. Peale and I failed to observe any locality where there was a lateral change in the color of this sandstone, and the conditions as we saw them appeared to indicate a slight unconformity. Moreover, the inherent probability that this may be correctly interpreted as an unconformity is indicated by the fact that the massive sandstone marked the close of marine conditions in this region, and further by the fact, as will be shown in a future publication, that the abundant flora gives evidence of being younger than Laramie.

POINT OF ROCKS, WYOMING, AND VICINITY.

With the possible exception of Black Buttes, no locality in this region has given rise to more extended discussion than Point of Rocks. The section is well exposed in the bluff just north of the station and consists of massive white sandstones and soft clay shales and coal beds. The plants have been found mainly in proximity to the coal. These beds constituted the "Point of Rocks series" of Powell and were described by him as strongly unconformable beneath the "Bitter Creek series." Powell, Meek, and White agreed in regarding these beds as of Cretaceous age, but Lesquereux from his studies of the plants considered them as Tertiary. After the Laramie formation was established the beds at Point of Rocks were referred by White and others to this formation, or group, as it was then called, and this disposition remained undisputed for many years.

In 1897 Stanton and I [24] pointed out that the coal and plant bearing beds at Point of Rocks are below marine Cretaceous beds containing a Fox Hills fauna and hence could not be of Laramie age. The statement was as follows:

> At Point of Rocks, 11 miles northwest of Black Buttes, a lower series of coal-bearing beds is well exposed in cliffs and high hills north and east of the station. Here, as at Black Buttes, the base of the exposure is formed by a massive light-colored sandstone about 100 feet thick, and this fact, together with evidence of local faulting along the railroad between the two places, has led several geologists to regard the two exposures as representing about the same horizon. Our observations confirm those of Meek and Bannister in putting the Point of Rocks coal beds several hundred feet lower than those at Black Buttes, and we discovered the additional fact that a considerable portion of the intervening strata consists of marine beds and contains a Fox Hills fauna. The uneven upper surface of heavy sandstone at Point of Rocks was regarded by Powell as evidence of an erosion interval which separated the Point of Rocks group below from the Bitter Creek group above. The larger number of fossil plants described from this locality were obtained in argillaceous lenticular masses in the upper part of the sandstone. Others are associated with the coal beds, of which there are several in the series of soft sandstones, sandy shales, and clays exposed in the bluffs north of Point of Rocks station to a thickness of about 260 feet above the massive sandstone. Above the middle of the coal-bearing part of the section two fossiliferous bands have yielded a few species of invertebrates, consisting of one marine shell, four brackish-water forms, and one fresh-water form. * * *
>
> In the neighborhood of Point of Rocks the dip of the beds is about 6° a little north of east, almost parallel with a valley that joins that of Bitter Creek just east of the station, so that the heavy sandstone soon disappears beneath the surface and the beds above it successively come down to the valley level in the hills on its north side. * * * The beds on the top of the bluffs north of the station thus come down to the valley a little over a mile east of that place, and immediately above them, in a brown ferruginous sandstone, marine Cretaceous species indicating a Fox Hills horizon were found. * * *
>
> Above this horizon there are few exposures seen on going eastward until a line of cliffs is reached nearly 4 miles east of Point of Rocks. These cliffs show at their base about 150 feet of clay shales with bands of sandstone, and a concretion in the clay yielded *Baculites ovatus* Say, *Lunatia occidentalis* Meek and Hayden, and *Mactra* sp., showing that this horizon, some 700 feet above the last one mentioned, is still in the Fox Hills. The shales are overlain by massive sandstone somewhat over 100 feet thick, yellowish brown below and nearly white above, and this is succeeded by a series of shales, sandstones, and coal

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[24] Stanton, T. W., and Knowlton, F. H., Stratigraphy and paleontology of the Laramie and related formations in Wyoming: Geol. Soc. America Bull., vol. 8, p. 146, 1897.

beds like that at Black Buttes and containing many of the same characteristic species of fossils in the sane stratigraphic order.

As already pointed out, the coal and plant bearing section at Point of Rocks had for many years been regarded as belonging in the Laramie, and the flora especially had come to be known as a "true Laramie flora," although it had long been recognized that it was "somewhat different from that of any other locality in the West." In accordance with the discovery above set forth, that the coal and plant-bearing rocks were some hundreds of feet below well-defined marine Cretaceous, a readjustment became necessary. These facts are set forth at some length in my paper on the "Flora of the Montana formation," [25] published in 1900.

In the summer of 1907 A. R. Schultz [26] and party investigated the resources of the northern portion of the Rock Springs field and gave a brief account of the geologic relations. The Point of Rocks coal and plant bearing beds, as well as the upper coal measures at Rock Springs, were called the Almond coal group, which was referred to the Mesaverde formation. It is separated by the marine Lewis shale (750± feet) from the overlying Black Buttes coal group, which was classed as Laramie (?). Schultz's results thus confirmed the observations of Meek and Bannister regarding the placing of the Black Buttes coal beds well above the Point of Rocks coals and those of Stanton and Knowlton in recognizing a marine Cretaceous formation between the two groups of coals.

In 1908 Schultz [27] continued this study to include the southern part of the Rock Springs field. No change was made in the stratigraphic assignment of the coal and plant bearing beds under consideration.

SOUTHWESTERN WYOMING.

Within an area about 40 miles wide and 175 miles long, in Uinta and Lincoln counties, in the extreme southwest corner of Wyoming, there are numerous economically important deposits of coal, and the area has been often visited and more or less critically studied by geologists. The geologic relations in the vicinity of Evanston have been frequently alluded to in the first portion of this discussion, and hence it is only necessary in this connection to call attention to a few of the more salient points before reviewing the present accepted status.[28]

In connection with the coal at Evanston fossil plants were discovered at an early day, and the locality has been studied by Hayden, Peale, Lesquereux, Newberry, Ward, and many others. Lesquereux [29] always regarded the plants as indicating a Tertiary age, and in his final report he placed the Evanston locality in his so-called "second group," which included also Mount Bross and Troublesome Creek, in Middle Park, Colo., and Bridger Pass, Wyo. Newberry [30] expressed the opinion that these plant beds, as well as practically all lignite-bearing beds in Wyoming and Utah, were Cretaceous, and hence when the Laramie was established they were naturally referred to this time division. In 1878 C. A. White [31] included the "Evanston coal series" in the Laramie and gave a list of four species of invertebrates common with the Judith River beds.

In his "Synopsis of the flora of the Laramie group" Ward [32] described a number of plants from Evanston and Hodges Pass; the latter locality, he stated, "may be regarded as forming a northern member of the Evanston coal field." Evanston and Carbon were placed together in the table showing the extent and range of the Laramie flora as he accepted it, and both were regarded as belonging in its upper portion.

Two years later White [33] went a step further and referred the coal-bearing series at Evanston to the Wasatch on the ground that sedimentation was continuous from the undoubted Cretaceous through the Laramie and into the Wasatch, and, moreover, the invertebrates, before supposed to be characteristic of the

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[25] Knowlton, F. H., U. S. Geol. Survey Bull. 163, 1900.

[26] The northern part of the Rock Springs coal field, Sweetwater County, Wyo.: U. S. Geol. Survey Bull. 341, pp. 256-282, 1909.

[27] The southern part of the Rock Springs coal field, Sweetwater County, Wyo.: U. S. Geol. Survey Bull. 381, pp. 214-281, 1910.

[28] A complete bibliography of works relating to the geography and geology of this region is given by A. C. Veatch (Geography and geology of a portion of southwestern Wyoming: U. S. Geol. Survey Prof. Paper 56, pp. 17-32, 1907).

[29] Lesquereux, Leo, The Tertiary flora: U. S. Geol. Survey Terr. Rept., vol. 7, 1878.

[30] Newberry, J. S., On the lignites and plant beds of western America: Am. Jour. Sci., 3d ser., vol. 7, p. 400, 1874.

[31] On the distribution of molluscan species in the Laramie: U. S. Geol. and Geog. Survey Terr. Bull., vol. 4, p. 722, 1878.

[32] Ward, L. F., U. S. Geol. Survey Sixth Ann. Rept., for 1884-85, pp. 541 et seq., 1886.

[33] White, C. A., On the relation of the Laramie molluscan and fresh-water Eocene fauna to that of the succeeding fresh-water Eocene and other groups: U. S. Geol. Survey Bull. 34, pp. 9-16, 1886.

Laramie, were then found to be more closely related to those of the Wasatch or later beds.

In 1895 Wilbur C. Knight [34] published a paper on the "Coal and coal measures of Wyoming," in which he stated that coal-bearing beds" are found at "Henrys Fork, Almy, Twin Creek, Hams Fork, and Coalville [Cokeville]. The last four localities are probably in the same coal field, which belongs to the Lower Cretaceous and has been known as the Bear River group." This view was widely at variance with the facts even as then understood and has not been followed.

The following year (1896) Stanton and I [35] spent a few days at Evanston and Hodges Pass and concluded that the Wasatch was probably unconformable on the coal-bearing beds, which were presumed to be in the upper part of the Laramie.

In the summer of 1905 A. C. Veatch [36] and party began an investigation of the coal and oil resources of this region and presented a short preliminary statement of results, which was published the next year. The several formations observed and mapped, with their geologic time values, were set forth in the form of a table. The uppermost Cretaceous formation, with a thickness of over 5,000 feet, was referred to the Laramie. It was said to include the Adaville-Lazeart coal, 10 to 84 feet thick, and to be terminated at the top by a marked unconformity. To the beds above the unconformity, which included the coal at Evanston—that is, the bed worked at the Almy and Red Canyon mines—the name Evanston formation was given, but the exact age determination was left questionable.

Veatch's complete report on this area [37] was published a year or more later, and in this the geologic and paleontologic data were reviewed in full. The uppermost member of the Cretaceous section, called Laramie in the preliminary report, was here called the Adaville formation, which included also a white basal sandstone denominated the Lazeart sandstone member. A few hundred feet of the basal part of the Adaville formation was thought to be of Montana age, and the remainder of the 5,000 feet was called "Lower Laramie." Fossils were found only in the lower part of this formation, and both plants and invertebrates appeared to indicate an age older than Laramie, and these furnished the basis for placing the lower portion in the Montana.

The unconformity at the top of the Adaville formation ("Lower Laramie"), according to Veatch, involved a long period of folding, faulting, and erosion, inferred on stratigraphic grounds and indicating the removal of over 20,000 feet of strata.

In the geologic column given by Veatch [38] the overlying Evanston formation was referred without qualification to the "Upper Laramie" and made the basal member of the Eocene, but in the discussion of this formation [39] this reference was not quite so positively stated. On this point Veatch wrote as follows:

> The Evanston formation was considered by the geologists of the early Government expeditions as Laramie. Later Dr. White, after studying in detail its invertebrate fauna and comparing it with that found at Wales, Utah, concluded that these beds were undoubtedly Wasatch. Ward and Knowlton, because of its flora, have regarded it as essentially the same as the Carbon beds, but as the stratigraphic position of the Carbon beds has never been determined this correlation does not lead very far. Knowlton reported that the leaves collected in 1905 are "Upper Laramie." As early as 1893 he suggested the possibility of their representing the Denver beds, and again, in 1898, doubtfully referred this locality to the Denver. Dr. T. W. Stanton regards the invertebrates as Laramie or Fort Union, and the question thus becomes involved in the larger one of the true age of the Fort Union, which has been regarded both as Upper Cretaceous and Eocene. The paleontologic collections made at this locality do not prove conclusively that the beds are Upper Cretaceous or, on the other hand, show that they are basal Eocene. * * * The stratigraphic evidence strongly suggests that the line between the Eocene and the Cretaceous should be drawn at the base of the Evanston and certainly shows no reason for drawing it between the Evanston and the Almy [the formation conformably above the Evanston]. On the whole, the Evanston formation may be tentatively regarded as Eocene.

The reference of the Adaville and Evanston formations to the "Lower Laramie" and "Upper Laramie," respectively, was in accord with the section as worked out in Carbon County, Wyo., even including the great unconformity separating them.

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[34] U. S. Geol. Survey Sixteenth Ann. Rept., pt. 4, pp. 208-212, 1895.

[35] Stanton, T. W., and Knowlton, F. H., Stratigraphy and paleontology of the Laramie and related formations in Wyoming: Geol. Soc. America Bull., vol. 8, p. 148, 1897.

[36] Coal and oil in southern Uinta County, Wyo.: U. S. Geol. Survey Bull. 285, p. 331, 1906.

[37] Veatch, A. C., Geography and geology of a portion of southwestern Wyoming: U. S. Geol. Survey Prof. Paper 56, 1907 [1908].

[38] Idem, facing p. 50.

[39] Idem, pp. 76-87.

In 1906 A. R. Schultz[40] continued the field work directly north of the area covered by Veatch in the report just considered, but his report was not published until 1914. When the field study was made the area covered by Schultz was in the northern part of Uinta County, but subsequently (1912) this area was included in Lincoln County. In the main the geologic formations present in the southern area were carried northward into Lincoln County, though with some notable changes in the thickness of the beds. The Adaville formation showed a decrease in thickness from a maximum of 4,000 to 2,800 feet, and the Evanston an increase from 1,600 to over 9,500 feet. Both these formations were described in much the same terms as were used by Veatch; in fact, full quotations were made from his report. No stratigraphic or paleontologic evidence was procured or recorded concerning them that would tend to change their age assignments as recorded by Veatch, yet in the stratigraphic column given on page 29 of Schultz's report striking modifications appeared. Thus the Adaville was placed entirely in the Montana, and the designation "Lower Laramie" had disappeared, while the Evanston, before called "Upper Laramie" and made the basal member of the Eocene, was here placed under the designation "Cretaceous or Tertiary," and the Almy formation became the lowest accepted Eocene.

COALVILLE, UTAH, AND VICINITY.

The geology in the vicinity of Coalville, Utah, is somewhat complicated, and extensive differences of opinion on it have prevailed among geologists. The following brief historical account of it is given by T. W. Stanton:[41]

> The coal-bearing Cretaceous beds exposed at Coalville, Utah, and on Bear River, near the mouth of Sulphur Creek, Wyo., have been the subject of considerable discussion, and various opinions concerning their precise age have been published by several geologists and paleontologists who have visited the localities or examined collections from them. They were referred to the Cretaceous by Messrs. Meek and Engelmann in 1860 and were compared with certain Cretaceous beds at the mouth of Judith River, then regarded as belonging to No. 1 (Dakota) but afterward proved to be of Fox Hills age. When Capt. Simpson's report was published in 1876 Mr. Engelmann again expressed the opinion that these beds are probably "Lower Cretaceous" [Dakota].
>
> They were at first regarded as Tertiary by Messrs. Hayden and Lesquereux. In 1870 Messrs. Meek and Hayden adopted the view that the Coalville beds are Cretaceous but that they "occupy a higher horizon in the Cretaceous than even the Fox Hills beds of the Upper Missouri Cretaceous series."
>
> Mr. Meek visited Coalville in 1872, and after making larger collections and studying the stratigraphy he decided that the entire upper Missouri Cretaceous section, with perhaps some older beds, is represented here. The detailed section that he published shows correctly the essential features of the stratigraphy. The opinions that he then expressed concerning the correlation of these beds were repeated in subsequent publications.
>
> Messrs. King and Emmons assigned the Cretaceous strata at Coalville to the Colorado, Fox Hills, and Laramie formations and so mapped them in the atlas accompanying their report. The principal (lower) coal bed is included in the Colorado formation and the upper one in the Fox Hills, the line between these two formations being drawn in the second ridge above the lower coal bed. It should be remembered that the Colorado formation was then made to include the Fort Pierre division.
>
> Dr. C. A. White studied the section in 1877, and after discussing the fossils collected in it, he states that it is impracticable to refer the strata to any one or more of the established Cretaceous groups with certainty, but he thinks there is no reason to doubt that the greater part of the series at least is referable to the Fox Hills.

Stanton presented a detailed section, which shows the presence of about 6,000 feet of strata below the recognized Tertiary. Of this column about 1,700 feet was assigned to the Colorado, about 2,800 feet tentatively to the Montana, and approximately 1,500 feet of unfossiliferous strata were said to include the Laramie if it is present.

None of the investigators prior to Stanton had noticed the presence of plants, but he found a fairly rich deposit nearly 1,000 feet above the base of the Montana, overlain by fully 1,800 feet of richly fossiliferous marine Cretaceous, representing the upper portion of the Montana.

These plants were studied by me, and a brief report on them is printed on page 42 of Stanton's bulletin. In this report it was stated that the most important of the species "belong clearly to the Laramie group," but it should be remembered that this statement was in accord with the current conception of the Laramie when the flora from Point of Rocks was regarded as typical. The subject was reviewed and the plants from Coalville properly referred to the Montana in my "Flora of the Montana formation." [42]

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[40] Schultz, A. R., Geology and geography of a portion of Lincoln County, Wyo.: U. S. Geol. Survey Bull. 543, 1914.

[41] The Colorado formation and its invertebrate fauna: U. S. Geol. Survey Bull. 106, pp. 37, 38, 1893 [1894].

The economic resources of this region were briefly examined by J. A. Taff [43] in 1906, but he made only incidental mention of the geologic relations, taken mainly from the results of the earlier students.

The Coalville section was also briefly summarized by A. C. Veatch [44] in his paper on the "Geography and geology of a portion of southwester Wyoming," published in 1908, for the purpose of comparing it with the Wyoming section, of which it doubtless represents a part. He suggested that the Colorado group may extend higher in the section so as to include the plant-bearing beds. Veatch also gave a very complete bibliography relating to the exploration and geology of this general region. The latest report on this field is that by Carroll H. Wegemann,[45] published in 1915. In this report the Coalville section, with a thickness of about 9,000 feet, was described as a slightly overturned anticline. Folding and faulting here further complicated matters until in the absence of adequate paleontologic data, it is difficult to draw satisfactory formational boundaries; in fact, Wegemann stated that "although the area has been studied by several geologists, the formation boundaries are by no means definitely determined."

According to Wegemann, the workable coal of the region is of Colorado age, but the thickness that is to be assigned to the Colorado part of the section is indefinite. Its thickness is at least 1,000 feet, and there is a tendency to extend the Colorado upward to include an additional 1,000 feet, but the evidence for this was not regarded as conclusive. It would then include the plant horizon already mentioned, which contains a flora correlated with the Montana (Mesaverde) at Point of Rocks, Wyo.

The Laramie is not known to be present in this section, but in this connection Wegemann pointed out that there are over 4,000 feet of beds between those last mentioned and the unconformity at the base of the Tertiary (Wasatch formation) that are still unplaced. This great thickness of beds was divided into two parts, the lower of which (No. 3 of Wegemann's section on p. 163), 1,650 feet thick, is marine, while the upper (No. 2), 2,500 feet thick, contains leaves and fresh-water shells, though they are not sufficiently abundant or sufficiently well preserved to admit of definite stratigraphic determination.

SAN JUAN BASIN AND ADJACENT AREAS IN COLORADO AND NEW MEXICO.

The area included in the San Juan Basin and vicinity extends from the vicinity of Durango, Colo., on the north, beyond Gallup and Mount Taylor, N. Mex., on the south, and from a point near the Arizona-New Mexico line on the west to Chama, Elvado, and the Sierra Nacimiento, near the longitude of Albuquerque on the east, or nearly 150 miles from north to south and 100 miles from east to west. The coal-bearing rocks form a more or less continuous rim around this basin and dip toward the center, where, however, they are deeply buried.

The San Juan district was studied by W. H. Holmes,[46] of the Hayden Survey, in 1875. In Plate XXXV of his report he gave a general section of the rocks in the valley of San Juan River. The uppermost member was referred to the Wasatch, which he divided into two parts, the lower being the Puerco marl of Cope. Immediately below this is the so-called "upper coal group," made up of 800 feet of soft sandstones and marls, which was referred to as Laramie ?. This in turn rests on the Pictured Cliff sandstone, which with the underlying 1,500 to 2,000 feet of rocks Holmes referred to the Fox Hills.

Except for a number of economic reports on the coal of the region, little systematic work was done in this area until 1899, when Whitman Cross,[47] in the La Plata folio, established the units of the Upper Cretaceous section of the region, which have subsequently been so widely identified in Colorado, Wyoming, and Montana. These units in ascending order are Mancos shale, Mesaverde formation, and Lewis shale. Concerning the Lewis Cross wrote as follows:

> Above the Mesaverde formation occurs another formation of clay shale, reaching an observed thickness of nearly 2,000 feet, which is very much like the Mancos shale but contains fewer fossils. The only identifiable form thus far found in this shale occurs also in the Mancos shale, so

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[42] Knowlton, F. H., U. S. Geol. Survey Bull. 163, pp. 8-9, 1900.

[43] Notes on the Weber River coal field, Utah: U. S. Geol. Survey Bull. 285, pp. 285-288, 1906.

[44] U. S. Geol. Survey Prof. Paper 56, p. 103, 1907 [1908].

[45] The Coalville coal field, Utah: U. S. Geol. Survey Bull. 581, pp. 161-184, 1915.

[46] Geological report on the San Juan district: U. S. Geol. and Geog. Survey Terr. Ninth Ann. Rept., p. 241, 1877.

[47] U. S. Geol. Survey Geol. Atlas, La Plata folio (No. 60), p. 4, 1899.

> that this division is still apparently below the true Fox Hills. This formation is called the Lewis shale.

Continuing, Cross said:

> Still above the Lewis shale is a second series of sandstones, shales, and coals, bearing some resemblance to the Mesaverde formation but differing in detail. The lowest member of this complex is the "Pictured Cliff sandstone" of Holmes's San Juan section, which he placed in the Fox Hills upon the evidence of invertebrate remains. The remainder was referred to the Laramie, but without fossil evidence. The present survey has also failed to bring to light valid ground for assigning any of the beds in question to the Laramie, while there is some reason to believe that more than the lower sandstone belongs to the Montana group.

In 1905 F. C. Schrader [48] made a preliminary or reconnaissance examination of the Durango-Gallup coal field, in which he adopted the stratigraphic classification established by Cross, the uppermost coal-bearing sandstone being classed as Laramie?, though no fossil evidence was presented.

In 1906 more detailed examinations were made in the region by Joseph A. Taff and M. K. Shaler. Taff [49] considered the Durango coal district, which lies just off the southern foothills of the San Juan and La Plata mountains. In this report the upper coal-bearing rocks here under consideration were referred without question to the Laramie, though no details were given as to the reasons for this reference. Shaler's report [50] deals with that part of the Durango-Gallup field lying west of longitude 107° 30′. The beds here in question were also referred to the Laramie without qualification, on the basis, as he stated, of fossils studied by T. W. Stanton and me, though the evidence was not presented in detail. Examination of the original reports on the plants collected by Shaler and others in this region shows that the collections were few and fragmentary and the tendency was to regard them as older than Laramie.

The status of the "Laramie" in the region under consideration is so succinctly summed up by W. T. Lee [51] in his paper on the "Stratigraphy of the coal fields of northern New Mexico" that his remarks are quoted entire as follows:

> The "Laramie" formation occurs within the area described in this paper only in the San Juan Basin. It is more than 1,000 feet thick in the southern rim of the basin but is thinner in the eastern rim, probably due to post-Cretaceous erosion. At Dulce it is only 225 feet thick. The formation lies conformably on Lewis shale and probably for this reason more than for any other has been called Laramie, although Dr. Cross several years ago called attention to the fact that investigation had "failed to bring to light valid ground for assigning any of the beds in question to the Laramie, while there is some reason to believe that more than the lower sandstone belongs to the Montana group." Since that time a considerable number of fossils, both of invertebrates and of plants, have been collected from these beds in the Durango region. The base of the formation—the Pictured Cliff sandstone—contains marine invertebrates, and the lower part of the coal-bearing rocks above this sandstone contains brackish-water invertebrates, several of which occur in the Mesaverde of other fields. But higher in the formation the rocks contain fresh-water invertebrates which Dr. Stanton regards as Laramie and fossil plants which Dr. Knowlton regards as older than Laramie. The fossil plants have been given in the table previously given, and from this table, as well as from the accompanying statement by Dr. Knowlton,[52] it will be seen that the flora differs but little from that of the Mesaverde farther to the south.
>
> The name "Laramie" is here used for this formation not because the writer wishes to argue for the Laramie age of the rocks, but because the name is in use and because in this paper the writer is intentionally avoiding the introduction of new names for rock formations. It must be noted, however, that while the formation is called "Laramie" it contains a flora which denotes Montana age, having nothing in common with the Laramie flora of the Denver Basin.
>
> Whether the formation will eventually be called "Laramie" or be designated in some other way depends largely on the final use of that somewhat migratory name. But in view of the facts that many of the species of marine and brackish-water invertebrates from the lower part of the formation occur in the Mesaverde of other localities, that the invertebrates from the upper part are of fresh-

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[48] The Durango-Gallup coal field of Colorado and New Mexico: U. S Geol. Survey Bull. 285, pp. 241-258, 1906.

[49] The Durango coal district, Colo.: U. S. Geol. Survey Bull. 316, pp. 321-337, 1907.

[50] A reconnaissance survey of the western part of the Durango-Gallup coal field of Colorado: Idem, pp. 376-426.

[51] Geol. Soc. America Bull., vol. 23, pp. 607-608, 1912.

[52] The statement here alluded to is as follows: "Near Dulce, N. Mex., and near Durango, Colo., there have been obtained two collections of plants from above the Lewis shale in coal-bearing rocks that have been referred to the so-called 'Laramie' of this region. These collections are very full and embrace a number of easily recognized species, hence their identification is satisfactory and complete. These collections prove clearly that these beds do not belong to the Laramie, since, so far as known to the writer, not a single species there present has been found in beds of this age. On the other hand, the plants indicate beyond question that they belong to the Montana, there being, for instance, *Ficus speciosissima*, *Ficus* sp. (narrow, 3-nerved type), *Ficus* sp., type of *F. lanceolata*, a palm, etc., which link them with the Mesaverde floras to the south and the beds already discussed in the Raton Mesa region. Associated with these, however, and tending to give them a slightly higher position, though still within the Montana, are such forms as *Brachyphyllum*, *Cunninghamites*, *Geinitzia*, *Sequoia*, etc., all of which are beyond doubt Montana types not found in the Laramie.

A number of collections were made by J. H. Gardner in the Ignacio quadrangle, east of Durango, Colo., from beds regarded as the Laramie of that area. The plants in these collections, almost species by species, are identical with the forms from Dulce and near Durango, and I have no hesitation in saying that they occupy the same stratigraphic position and are the same in age, viz, Montana."

> water origin and admittedly unreliable for purposes of correlation, and that the plants are of Montana types, serious doubt is cast on the Laramie age of the formation.

It now remains to consider certain dinosaur-bearing beds near Ojo Alamo, N. Mex., 12 miles south of Farmington, which may have a bearing on the "Laramie" of the San Juan Basin. In 1908 James H. Gardner, then of the United States Geological Survey, found vertebrate remains near the head of Coal Creek, 1 mile southeast of Ojo Alamo, "in variegated sands, shales, and conglomerates, indisputably above the unconformity at the top of the Laramie."[53] These remains were studied by C. W. Gilmore, who reported the presence of *Triceratops*, *Trachodon*, *Tyrannosaurus*, *Aspidiretes*, and crocodiles, which, he said, "appears to represent a typical fauna of the so-called Laramie, or better, *Ceratops* beds." At the time this was written it was thought possible that these dinosaur-bearing beds might be a part of the Puerco formation, but subsequent investigation has shown that this is not so.

In the same year (1909) Stanton[54] listed several collections of invertebrates from the so-called Laramie "coal measures immediately above the Lewis shale," on the line between La Plata and Archuleta counties, Colo., which he considered as belonging to the same fauna and "at about the same horizon" as the fauna in the beds at Black Buttes, Wyo.

It appears that dinosaurs had been known at the Ojo Alamo locality as early as 1902, but it was not until 1904 that a systematic attempt was made to collect them. In that year Barnum Brown, of the American Museum of Natural History, made a reconnaissance trip to the locality and procured "a small but interesting collection of fossils." His report on these fossils, however, was not published until 1910.[55] He said:

> This collection is of special interest, as it represents a fauna that is distinctly older than that of the "Lance Creek beds or *Ceratops* zone" and "Hell Creek beds" of the Laramie Cretaceous. I am unable definitely to correlate the horizon in which these bones occur, but the faunal facies appears to be even older than that of Black Buttes, Wyo., and probably represents a period synchronous with the lower part of the Edmonton series of Alberta, Canada. * * *
>
> Less than a mile south of the store at Ojo Alamo the Puerco formation rests unconformably on a conglomerate that is composed of red, gray, yellow, and white pebbles. The position of these beds is below what may be called the type of the Puerco or basal Eocene, and their unconformable relation is highly significant. * * * Below the conglomerate there is a series of shales and sandstones, evenly stratified and usually horizontal, in which there is much less cross-bedding than commonly occurs in the Laramie of the northern United States.
>
> The shales below the conglomerate that contain numerous dinosaur and turtle remains I shall designate as the Ojo Alamo beds. They are estimated to be about 200 feet thick, but owing to lack of time I was unable to determine their relation to the underlying formations. The vertebrate remains were numerous in several places from 30 to 100 feet below the conglomerate.

The new dinosaurian was described as *Kritosaurus navajovicus*.

During the summer of 1909 James H. Gardner, in company with James W. Gidley, of the United States National Museum, spent two days in the vicinity of Ojo Alamo and obtained a number of remains of turtles from Brown's Ojo Alamo beds. These were described by O. P. Hay[56] the following year. Concerning the stratigraphic relations Hay said:

> In this region they found two distinct formations. In the lower, composed of sandstones, clays, and a bed of conglomerate, there were found fragmentary remains of dinosaurs and the turtles below described. * * * These beds are probably the equivalent of the Lance Creek beds.

Also in 1910 Gardner[57] published a paper on "The Puerco and Torrejon formations of the Nacimiento group," which involved, incidentally, the beds under discussion. He recorded the Puerco as resting unconformably on the "Laramie" of the region, as Brown had reported, and he stated that at Ojo Alamo he "obtained dinosaurs from beds unconformably above the 'Laramie' and below the Wasatch." These beds are, of course, the Ojo Alamo beds of Brown, and Gardner's discovery tended to establish the fact that these dinosaur-bearing beds rest unconformably on the "Laramie" and are unconformably overlain by the Puerco.

An expedition from the American Museum of Natural History, under the charge of W. J.

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[53] Knowlton, F. H., The stratigraphic relations and paleontology of the "Hell Creek beds," "*Ceratops* beds," and equivalents: Washington Acad. Sci. Proc., vol. 11, p. 233, 1909.

[54] Stanton, T. W., The age and stratigraphic relations of the "*Ceratops* beds" of Wyoming and Montana: Washington Acad. Sci. Proc., vol. 11, p. 274, 1909.

[55] Brown, Barnum, The Cretaceous Ojo Alamo beds of New Mexico, with description of the new dinosaur genus *Kritosaurus*: Am. Mus. Nat. Hist. Bull., vol. 28, pp. 267-274, 1910.

[56] Descriptions of eight new species of fossil turtles from west of the one hundredth meridian: U. S. Nat. Mus. Proc., vol. 38, pp. 307-326, 1910.

[57] Gardner, J. H., Jour. Geology, vol. 18, pp. 702-741, 1910.

Sinclair and Walter Granger,[58] spent the season of 1913 in collecting fossils from the Puerco and Torrejon formations of New Mexico. Although these authors were concerned mainly in procuring mammal remains from the formations mentioned, they recorded certain important observations on the underlying dinosaur-bearing or Ojo Alamo beds. They agreed with Brown and Gardner in finding the Puerco resting with marked erosional discordance on the underlying beds. The reptilian and other vertebrate material procured by Sinclair and Granger from the Ojo Alamo beds was studied by Brown, whose report they quoted. From this it appears that Brown's *Kritosaurus* was regarded as generically identical with *Gryposaurus*, described later by Lambe[59] from the Belly River formation of Canada. Continuing, Brown said:

> The fauna of the Ojo Alamo beds is certainly older than that of the Lance, and I have expressed the opinion that it is probably synchronous with the Edmonton. *Kritosaurus* is now known from the Belly River beds and has not yet appeared in extensive collections from the Edmonton, and as other reptilian remains are of primitive facies the Ojo Alamo beds may well be of Judith River age.

Sinclair and Granger did not attempt to reach any decision concerning the age of the Ojo Alamo beds, though they gave an alternative hypothesis, as follows:

> Willis T. Lee favors a correlation of the dinosaur beds and associated conglomerate members with the Animas formation. If the Animas is in turn to be correlated with the Lance, * * * then the line between Cretaceous and Tertiary in the Ojo Alamo region would have to be drawn * * * not at the unconformity below the Puerco, where the vertebrate paleontologist would incline to put it, but at some level not yet discovered.

The probable correlation of the Ojo Alamo beds was suggested by me[60] as follows:

> The Puerco formation rests unconformably on dinosaur-bearing beds, beneath which is the "Laramie" of the region. I have shown elsewhere, however, that these later beds are undoubtedly much older than Laramie. The "*Ceratops* beds," immediately beneath those containing the Puerco fauna, have been practically traced into the Animas formation, which Cross holds is of Denver age. The Animas formation is now known to extend eastward to the eastern border of the San Juan Basin, near Dulce, N. Mex., where it is conglomeratic at the base and consists of an andesitic matrix, in which are pebbles of many kinds of older rocks; above this conglomerate are Eocene leaves.

The last published contribution to the geology and paleontology of the San Juan Basin was made in 1916, when four short papers by C. M. Bauer, C. W. Gilmore, T. W. Stanton, and me were issued under the general caption "Contributions to the geology and paleontology of San Juan County, N. Mex."[61] The first paper of the series, by Bauer, was entitled "Stratigraphy of a part of the Chaco River valley" and was based on field work and collections made in 1915. The thesis of Bauer's paper he gave as "an attempt to set forth the principal features of the stratigraphy in a part of the San Juan Basin—to describe the succession of strata irrespective of possible correlations and thereby to establish a type section for the formations exposed and to bring out their relations to the strata immediately above and below."

In the complex generally designated by previous writers as Laramie Bauer was able to differentiate two additional formational units. The lower of these, called the Fruitland formation, rests conformably on the Pictured Cliffs sandstone, has a thickness of 49 to 275 feet, and contains the coal of the region. Conformably above this formation is the Kirtland shale, with a maximum thickness of 1,180 feet and including what is called the Farmington sandstone member, which reaches a thickness of 455 feet. Above the Kirtland is the Ojo Alamo sandstone of Brown. The relation between the newer and older interpretations was shown in the following table:

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[58] Paleocene deposits of the San Juan Basin, N. Mex.: Am. Mus. Nat. Hist. Bull., vol. 33, pp. 297-316, 1914.

[59] Lambe, L. M., Ottawa Naturalist, vol. 27, p. 145, 1914.

[60] Knowlton, F. H., Cretaceous-Tertiary boundary in the Rocky Mountain region: Geol. Soc. America Bull., vol. 25, p. 338, 1914.

[61] U. S. Geol. Survey Prof. Paper 98, pp. 271-353, 1916.

Older interpretations.	Bauer, 1916.
Wasatch.	Wasatch.
Torrejon.	Torrejon and Puerco.
Puerco.	
Laramie.	Ojo Alamo sandstone.
	Kirtland shale and Farmington sandstone member.
	Fruitland formation.
	Pictured Cliffs sandstone.
Lewis.	Lewis shale.
Mesaverde.	Mesaverde.

The second paper, by Gilmore, was entitled "Vertebrate faunas of the Ojo Alamo, Kirtland, and Fruitland formations." The vertebrates include dinosaurs, turtles, crocodiles, and fishes, and according to Gilmore they "are found throughout these deposits, though they appear to occur most abundantly in the Ojo Alamo and the upper part of the Kirtland, sparsely in and below the Farmington sandstone member of the Kirtland, and more abundantly in the Fruitland." His conclusion regarding their age was as follows:

> After a study of the material in the United States National Museum collections from this area, and after reviewing the literature in which specimens from these formations have been described, I conclude that the vertebrate remains from the Ojo Alamo, Kirtland, and Fruitland formations show beyond all question that they pertain to a fauna or faunas distinctly older than that of the Lance, and that such evidence as there is contributes to the support of Brown's contention that the Ojo Alamo sandstone is synchronous with the Judith River and Belly River formations as found in areas to the north.

The third paper, by Stanton, was entitled "Nonmarine Cretaceous invertebrates of the San Juan Basin" and dealt mainly with brackish and fresh water species from the Fruitland formation, only 2 of the 27 recorded species coming from the Kirtland shale and none from the Ojo Alamo sandstone. A table giving the stratigraphic range of these forms was presented and was discussed by Stanton as follows:

> The distribution of the species as exhibited in the table may seem at first glance to indicate that the Fruitland fauna is about as closely related to the Mesaverde and Judith River faunas (which are approximately contemporaneous with each other) as it is to the Lance and Laramie faunas. A closer analysis of the table, however, will show that most of the species occurring or represented by related forms in the Mesaverde and Judith River are long-lived brackish-water species which range at least as high as the Laramie. *Melania insculpta* belongs to this class, for like all the other American Cretaceous species referred to *Melania* it is invariably associated with brackish-water forms. The only two Fruitland species with an outside distribution which do not elsewhere range into the higher formations are *Modiola laticostata*, from the Mesaverde, and *Goniobasis? subtortuosa*, from the Judith River. With fresh-water species, especially those belonging to the genus *Unio*, the case is different. The majority of the identical and closely related species are found in the Laramie, the so-called "Lower Laramie" of southern Wyoming, and the Lance and do not range below these formations. It is my opinion, therefore, that the invertebrate evidence as a whole favors the assignment of the Fruitland formation to an epoch considerably later than Mesaverde and Judith River and possibly somewhat earlier than Lance. If due weight is given to the known stratigraphic relations and to the faunal evidence from the underlying formations, the Fruitland can hardly be older than Fox Hills, and the sequence from the base of the Fruitland up to the top of the Ojo Alamo, which is conformable, according to Mr. Bauer, may include the equivalents of everything from the Fox Hills to the Lance inclusive.

In my paper, on the "Flora of the Fruitland and Kirtland formations," the flora was discussed as follows:

> Of the 40 forms making up the known flora of the Fruitland and Kirtland formations, 16 have been found in other areas, and the list brings out the fact that no less than 15 of these forms are known to occur in the Montana. A further analysis of the list shows that 12 of the 15 forms occur in the Vermejo formation of Colorado and New Mexico, 10 occur in the Mesaverde, or rocks of about this age, in Wyoming and elsewhere, and 6 species are common to both these areas. On the basis of this showing the conclusion seems justified, therefore, that the Fruitland and Kirtland formations are of Montana age.

The material in a single small collection from the Ojo Alamo beds was so fragmentary that it could not be identified with satisfaction. Concerning it I said:

> It includes portions of a large leaf of unknown affinity, a small willow-like leaf, and a large leaf that appears to be an *Aralia* of the type of *Aralia notata* Lesquereux, a species very abundant and widely distributed in the Fort Union

formation. Nothing like this has been noted in the underlying beds, and to a certain extent it argues for the Tertiary age of the Ojo Alamo beds, though obviously the evidence is not strong. For the present, therefore, the dictum based on the evidence of the fossil vertebrates that these beds can not be separated from the underlying beds must be accepted, though the writer can not escape the impression that they may ultimately be shown to be of Tertiary age.

From the above exposition it appears that the plants and vertebrates are in substantial agreement in indicating a Montana age (Mesaverde or Judith River position) for the beds previously considered referable to the Laramie, whereas the invertebrates are interpreted as "indicating an epoch considerably later than Mesaverde and Judith River and possibly somewhat earlier than Lance."

"LARAMIE" IN WESTERN TEXAS AND NORTHERN MEXICO.

WESTERN TEXAS.

The extreme desirability of establishing a connection between the late Cretaceous and early Tertiary section of the great interior region and the well-authenticated marine section of the Gulf coast region has long been recognized. The Laramie in particular was one of the stratigraphic units characteristic of the Rocky Mountain region that it was hoped might sometime be brought into harmony with the marine succession of the Coastal Plain. C. A. White, who had taken so large a part in the exploitation of the Laramie and who was more or less familiar with both these areas, was especially desirous of establishing such a relation. In an article published in 1888 [62] he says:

> During the 12 years preceding the autumn of 1887, in which I had made extensive studies and observations concerning the Laramie group, I was never able to obtain any personal knowledge of the actual stratigraphic relation of that group to any of the marine Tertiary groups which border various portions of North America.

He then wrote of having studied the Laramie from the State of Nuevo Leon, Mexico, on the south, to northern Montana on the north, and added that within this vast region

> wherever any strata were found resting upon the Laramie they were always those of the great fresh-water Tertiary series; but I had not then traced the Laramie into a district within which marine Tertiary strata were known to exist. That is, in tracing the Laramie into Mexico I had followed the trend of that formation from the north and thus passed to the westward of the outcrops of the Gulf Tertiaries.
>
> In 1884 Prof. E. D. Cope [63] announced that he had found "the Claiborne beds resting immediately upon the Laramie at Laredo," Tex., but he then mentioned no correlated facts in support of this important announcement, and, so far as I am aware, none have since been published. The known southeastward trend of the Laramie and the circling and therefore converging trend of the Gulf series of formations made it evident that the district traversed by the lower Rio Grande would be found to be the most promising field in which to search for the stratigraphical relation between the Laramie and the Eocene Tertiary. With this object in view, I last autumn visited that region and had the satisfaction of confirming the observation previously made by Prof. Cope.
>
> Starting at Eagle Pass, Tex., I proceeded down upon the Texan side of the valley of the Rio Grande to Laredo, making observations by the way. The strata representing the Fox Hills group of the western section and the Ripley group of the eastern were found to dip gradually in the direction of the course of the river and to receive those of the Laramie group upon them, the older strata passing finally from view in that direction.
>
> The strata which are exposed in the bluffs along the left bank of the Rio Grande from 25 to 30 miles above Laredo and which bear one or more workable beds of coal there are referred confidently to the Laramie, although they afforded me only a few imperfect fossils. These strata dip gradually to the southeastward, or approximately in the direction of the river's course, and disappear beneath the sandy strata of the Eocene Tertiary some 10 or 12 miles above Laredo. Below this and all around Laredo the strata which I found exposed are of Eocene age, and in many places they bear an abundance of characteristic fossils.
>
> While I have no doubt as to the Laramie age of the strata referred to, which I observed on both sides of the Rio Grande, and none as to the Eocene age of the strata which I found overlying them, I am by no means certain that the lowermost strata which I found resting upon the Laramie near Laredo represent the lowermost strata of the Eocene division of the Gulf series. Indeed, so far as I could discover, no equivalent of the "Northern Lignite," the lowermost member of the Eocene of Hilgard's Mississippi section, exists in the region round about Laredo, unless the coal-bearing strata of the upper portion of the Laramie are really its equivalent. I am disposed to accept this view of the case and to regard the Northern Lignite of the Mississippi section and its equivalent elsewhere, including the uppermost strata of the Laramie, as really of Eocene age.

The view above expressed was entertained by White when he published his correlation paper on the Cretaceous in 1891.[64] He said:

> The Laramie formation prevails over a large part of the Great Interior area, but within the Texas region it has been recognized only in western Texas, and it has hitherto

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[62] White, C. A., On the relation of the Laramie group to earlier and later formations: Am. Jour. Sci., 3d ser., vol. 35, pp. 432-438, 1888.

[63] Cope, E. D., Am. Philos. Soc. Proc., vol. 3, p. 615, 1884.

[64] White, C. A., U. S. Geol. Survey Bull. 82, p. 117, 1891.

> been observed there only in the valley of the Rio Grande and in that of the Nueces River, but there seems to be little room for doubt that the lignite beds of eastern Texas, as well as those of the State of Mississippi, which are usually regarded as of early Eocene age, are really equivalent to the upper part of the Laramie.

The presence of the Laramie formation in western Texas, so confidently proclaimed by White, has not been confirmed by subsequent workers in this field; in fact, in the year following the publication of his paper above mentioned, Penrose[65] in a way laid the foundation for a quite different interpretation of the section. In speaking of the Cretaceous along the Rio Grande he said:

> It may be said, however, that Cretaceous fossils have been found at Eagle Pass, and from there down the river to the Webb County line are found great quantities of ammonites and other fauna of that epoch. In fact, it is not until we reach a point 3 miles below the northwest corner of Webb County that true Tertiary (or Laramie) forms are found.

In 1892 Dumble[66] studied this same section, concerning which he wrote as follows:

> From this point [10 miles below Eagle Pass] to the falls of the Rio Grande, just above the Webb County line, the exposures are but repetitions one of another—brown, buff, blue, or green clays, with sandstones, sometimes friable and sometimes so indurated as to be semiquartzites. Abundant fossils, consiting of ammonites (*Placenticeras*), oysters, and gastropods, are found. The rapids (or falls of the Rio Grande), which continue almost to the line between the two counties, are formed by the edges of some of these ammonite-bearing beds as they pass below water level. From this point to the Webb Bluff, a distance of 3 miles, no fossils were found; but there was no change in the lithologic character of the rock materials, nor could the clays at the base of the Webb Bluff section be distinguished in any way from those observed at the rapids above. * * * We have, therefore, only 3 miles in which there can be any room for deposits intermediate between strata containing fossils of recognized and decisively Cretaceous forms and those containing marine Eocene forms. The average dip does not exceed 100 feet per mile, and we saw nothing in any of the exposures on either bank of the river in this space to indicate a change until we reached Webb Bluff itself.

In 1900 Vaughan,[67] in a paper entitled "Reconnaissance in the Rio Grande coal fields of Texas," discussed the Cretaceous-Eocene contact along the Rio Grande. He agreed with White, Penrose, and Dumble that there is no sharp lithologic line between the Cretaceous and Eocene; in fact, no actual contact had been discovered up to that time. Vaughan added:

> The principal result of the writer's work on the Rio Grande was in proving the existence of Eocene fossils some 3 or 4 miles above the Webb-Maverick county line, 6 or 7 miles above where Penrose and Dumble first found such fossils. The fossils obtained here are typical lower Eocene.

In 1911 Dumble[68] published additional remarks on the Cretaceous-Eocene contact along the Rio Grande, in which he stated that the contact is "well shown below Toro Colorado, just above the falls of the Rio Grande and on Caballero Creek."

In the fall of 1912 L. W. Stephenson[69] made investigations in Maverick County, Tex., which, he said, "resulted in the exact determination of the Cretaceous-Eocene contact along the river [Rio Grande] and the approximate determination of the outcrop of the contact northward through the county." He found the contact at a point on the Rio Grande below White Bluff, about 5 miles above the Webb County line. At this point the undoubted Upper Cretaceous beds, known as the Escondido formation, are overlain unconformably by undoubted marine Eocene, the contact between them being sharp and slightly undulating.

The results above set forth appear to settle conclusively the fate of the Laramie of western Texas as advocated by White. The highest Cretaceous beds of the region are known as the Escondido formation and correspond approximately to the Fox Hills of the Rocky Mountain area and the Ripley formation of the Gulf coast. Above the Escondido formation are the beds referred by White to the Laramie, but all recent workers in the field agree that they are undoubtedly Eocene. The lowest is the Midway formation, above which is the Wilcox formation, which in turn is overlain, at least in certain areas, by the Claiborne or upper Eocene.

NORTHERN MEXICO.

So far as I know C. A. White was the first to announce that the Laramie is present in northern Mexico, a conclusion which of course followed from his supposed identification of this horizon along the Rio Grande in adjacent Texas. In a paper published in 1883 [70] he mentioned a small collection of invertebrates obtained at a point about 7½ miles northwest of Lampazos, in the State of Nuevo Leon. He enumerated seven species, as follows:

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[65] Penrose, R. A. F., jr., Texas Geol. Survey First Ann. Rept., pp. 38-41, 1889.

[66] Dumble, E. T., Geol. Soc. America Bull., vol. 3, pp. 228, 229, 1892.

[67] Vaughan, T. W., U. S. Geol. Survey Bull. 160, pp. 35 et seq., 1900.

[68] Dumble, E. T., Rediscovery of some Conrad forms: Science, new ser., vol. 33, p. 971, 1911.

[69] Stephenson, L. W., The Cretaceous-Eocene contact in the Atlantic and Gulf Coastal Plain: U. S. Geol. Survey Prof. Paper 90, pp. 155-182, 1915.

Ostrea wyomingensis Meek.
Anomia micronema Meek.
Modiola regularis White?
Corbula subundifera White.
Corbicula cytheriformis Meek and Hayden?
Odontobasis buccinoides White.
Melania wyomingensis Meek.

Concerning these invertebrates White said:

> This Mexican collection, so far as it goes, is an almost exact duplication of the Laramie molluscan fauna of the Bitter Creek series as found at Rock Springs, Point of Rocks, and Black Buttes, in southern Wyoming, points which are more than a thousand miles north of the Mexican locality.

The collection of invertebrates above listed is not now known to be in existence, but other similar material, collected later at or near the same locality by White, is preserved in the United States National Museum. I am informed by T. W. Stanton, in whose custody this material now is, that he does not accept all these identifications as being correct, and further, certain of the species have so great a known vertical range as to render them of slight stratigraphic value. The comparisons that White made between the Mexican specimens and the fauna of the "Bitter Creek series" shows that at least two horizons were then confused as Laramie.

In 1888, in an article already mentioned, White[71] again referred to this Mexican locality, writing as follows:

> Going westward from Laredo to Lampazos in Mexico I was able to recognize the Eocene strata for a distance of about 20 miles, beyond which the underlying rocks are so fully obscured by the débris of the plain that no exposures were observed until the neighborhood of Lampazos was reached. The known presence of Laramie strata a few miles to the northward of Lampazos, which bear characteristic molluscan fossils of that formation, however, leaves no room for doubt that the Laramie is overlaid by the Eocene upon the Mexican side of the Rio Grande, just as it is upon the Texan side.

This view was still entertained by White[72] when he published his correlation essay in 1891, for we find him saying:

> The Laramie, which is such an important formation in the two interior regions, is also an important one in the north Mexican region, especially in the States of Chihuahua, Coahuila, and Nuevo Leon. Its presence in the first-named State has just been mentioned, and it is also well developed in the Sabinas Valley, in Coahuila, where it is an important coal-bearing formation.
>
> It has also been recognized by its characteristic fossils as far south as the vicinity of Lampazos, in the State of Nuevo Leon. In this State, near to the Rio Grande, as well as on the Texan side of that river, it has been found to rest upon the equivalent of the Eagle Pass beds and in turn to pass by a gentle southerly dip beneath the marine Eocene beds which occur there.
>
> The stratigraphic relation of the Laramie to the immediately underlying Cretaceous formation is quite as intimate in the north Mexican region as it is elsewhere. The two formations appear to have been the result of continuous sedimentation, their interdelimitation being marked only by a material change in the paleontologic character of the strata.

For a decade or more after the above-recorded investigations by White comparatively little work bearing on the question under consideration was done in northern Mexico. As late as 1905, however, the Mexican geologists appear to have followed White in recognizing the presence of Laramie. Thus Aguilera,[73] in discussing the stratigraphy and structure of the State of Coahuila, accepted the Laramie and described it as consisting of glauconitic sandstones with impressions of plants and silicified wood. He placed it as equivalent to the upper part of his Esperanzas beds and above what has been called Eagle Pass formation in the Texan section.

E. T. Dumble has published several papers on the geology of northern Mexico, though relating mainly to the Tertiary part of the section. In one [74] he wrote of having traced the Cretaceous-Tertiary contact from Caballero, on the Rio Grande, to Rainones, 40 miles east of Monterey. The uppermost Cretaceous strata he referred to the Escondido formation.

The conclusions reached concerning the present disposition of the beds in western Texas that were formerly referred to the Laramie apparently apply with equal force to the similar beds in adjacent Mexico. That is to say, there is every reason to believe that the Eocene beds immediately above the Cretaceous line, which on the Texas side of the Rio Grande are referred to the Midway, continue without much if any change to the Lampazos region, in the the State of Nuevo Leon. Similarly, the beds in the coal-bearing area of northern Coahuila, south of Eagle Pass, are presumably the same as or similar to the coal-bearing series in the Eagle Pass region along the Rio Grande. According to my knowledge and belief the Laramie is not present in Mexico, or if there its presence must be demonstrated according to modern standards established for the recognition of this formation.

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[70] White, C. A., Late observations concerning the molluscan fauna and the geographical extent of the Laramie: Am. Jour. Sci., 3d ser., vol. 25, pp. 207-209, 1883.

[71] White, C. A., On the relation of the Laramie group to earlier and later formations: Am. Jour. Sci., 3d ser., vol. 35, p. 433, 1888.

[72] White, C. A., Correlation papers—Cretaceous: U. S. Geol. Survey Bull. 82, pp. 138 et seq., 1891.

[73] Aguilera, J. G., Les gisements carbonifères de Coahuila: Cong. géol. internat., 10^{e} sess., Guide des excursions, Mexico, No. 27, pp. 1-17, 1906 [1907].

[74] Dumble, E. T., Tertiary deposits of northeastern Mexico: Science, new ser., vol. 33, pp. 232-238, 1911.

JUDITH RIVER FORMATION.

The Judith River beds, in the vicinity of the mouth of Judith River, Mont., have been the subject of prolonged discussion and difference of opinion, and even at the present time there are some geologists who do not consider the question of age conclusively settled. As this question comes only incidentally into the present discussion, it is not necessary to go freely into the early history of opinion, especially as this has been so thoroughly covered up to 1905 by Stanton and Hatcher.[75]

At first Leidy's studies of the vertebrates inclined him to refer these beds to the Jurassic (Wealden). The invertebrates then known (1856) proved very puzzling. At one time they were considered by Meek and Hayden as possibly lowest Cretaceous, though they were described as Tertiary, and ultimately Meek considered it highly probable that they are Cretaceous. Marine beds immediately below the Judith River beds were identified as Fox Hills, and the beds immediately above as Fort Union. Cope, in 1875, from his extensive studies of the vertebrates, referred the beds to the uppermost Cretaceous but stated that the fauna has "some Tertiary affinities." By the time the Laramie was established by King, it had come to be generally accepted that the Judith River beds were stratigraphically and paleontologically in the proper position demanded by the definition of the Laramie, and hence we find C. A. White[76] referring to them as one of the subordinate groups or regional divisions of this group, as it was then called. He said (p. 865):

> The proof of the identity of these widely separated portions of the Laramie group consists in the recognition of various species of fossil mollusks in all of them that are found in some one or more of the others, thus connecting the whole by faunal continuity.

So far as the Judith River is concerned the above disposition was consistently held by White in all his subsequent publications, and the subject continued practically without essential change until 1905, when Stanton and Hatcher published the paper above mentioned. As the result of their studies in the original Judith River area, as well as in adjacent areas in northern Montana and along Milk River in Canada, they reached the conclusion that the Judith River formation is of Montana age and the equivalent of the Belly River beds of Canada. Their stratigraphic results and correlations are displayed graphically in the following section:

South Dakota.	Central and northern Montana.
Laramie.	Laramie (?).
Fox Hills.	Fox Hills (?).
Pierre.	Bearpaw. Judith River. Claggett. Eagle.

The Fox Hills and Laramie formations were not definitely identified by them in Montana.

The above interpretation regarding the Judith River was brought in question by A. C. Peale[77] in a long article published in 1912, in which he contended that there are two formations lithologically similar that have been confused, one being in the position of the Belly River and preferably to be called by that name, and the other—the real Judith River—being later than Fox Hills and probably to be regarded as equivalent to the lower part of the Lance formation.

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[75] Stanton, T. W., and Hatcher, J. B., Geology and paleontology of the Judith River beds: U. S. Geol. Survey Bull. 257, 1905.

[76] U. S. Geol. and Geog. Survey Terr. Bull., vol. 4, p. 721, 1878.

[77] On the stratigraphic position and age of the Judith River formation: Jour. Geology, vol. 20, pp. 530-549, 640-652, 738-757, 1912.

Peale's view was essentially sustained by Charles H. Sternberg, in a short paper published in Science for July 25, 1914, based on the recollection of 30 years before, when he had assisted Cope in collecting the vertebrate forms that later came into prominence in connection with this problem. In 1914, however, Sternberg again visited the region about the mouth of Judith River and completely reversed his conclusions as to the Tertiary age of the beds in question.[78]

The latest and most authoritative statement is that published by C. F. Bowen[79] in 1915, which presented the result of several seasons' work in this and adjacent areas. In general Bowen agreed with the statements of Stanton and Hatcher, namely, that the Judith River is the equivalent of the Belly River of Canada and is of Montana age. He recognized, however, that there was possibly some mixing of horizons in the earlier collections of vertebrate remains, as I pointed out[80] in regard to the turtles, and said that to this may be due the confusion that has resulted. Bowen wrote as follows:

> The extensive faulting that has disturbed the strata along Missouri River renders it possible, though it is not extremely probable, that blocks of the Lance formation may be faulted down among the beds of Judith River age and that some of the vertebrates collected by Hayden and others "from the badlands of the Judith" may have been obtained from the Lance formation instead of the Judith River formation, as they supposed.

The results obtained by Bowen, as set forth above, were essentially duplicated by Stebinger[81] in his work farther west in Montana, though he did not find it possible to recognize all the units present at the mouth of Judith River.

It therefore seems settled that the Judith River formation is not to be regarded as of Laramie age.

BEAR RIVER FORMATION.

The Bear River formation, as it is now called, has given rise to almost as much discussion and difference of opinion as the Judith River formation, just mentioned. It comprises a series of purely fresh-water strata of considerable areal extent, mainly in the valley of Bear River in southeastern Wyoming and adjacent Idaho. With the exception of a few unidentifiable fragments of dicotyledonous leaves and a single species of *Chara*—a fresh-water alga—its only paleontologic contents known are numerous invertebrates of fresh-water types and a few brackish-water forms. On account of the supposed affinities of these invertebrates the beds containing them were at first, in 1860, and for many years thereafter referred with little hesitation to the Tertiary. Then, as certain differences came to be detected, it was hinted by Meek and others that the age might possibly be latest Upper Cretaceous instead of Tertiary, and when the Laramie was promulgated the Bear River beds were immediately mapped by King and others—in this convenient catchall. They came later to be known as the "Bear River Laramie."

In 1891 T. W. Stanton[82] was able to show that this formation, previously considered to be of Laramie or later age, is in reality intermediate between the Jurassic and the Colorado Cretaceous. Of its thirty or more species of invertebrates none have been found in the true Laramie. Thus another supposed Laramie area has been eliminated. The complete historical summary of opinion regarding the Bear River formation may be found in two papers by C. A. White,[83] published in 1892 and 1895, to which the reader desiring further details is referred.

PRESENT USAGE OF THE TERM LARAMIE.

The term Laramie, as originally established by King, seemed to have a very definite signification and delimitation, but during the 40 years after it was first defined it had come, through faulty interpretation, mistaken stratigraphic identification, and general looseness of application, to have a somewhat varying and vicarious usage. It was undoubtedly established by King as a formational term, although, owing to lack of definiteness in stratigraphic nomenclature current then and later, it was sometimes alluded to as the "Laramie group," the "Laramie series," etc. As an instance of this latitude in the usage of the term, mention may be made of a recent textbook of geology, in which "Laramie series" is applied to all the beds between the Montana and the Fort Union, while "Upper Laramie" and "Lower Laramie" or "Laramie proper" are applied, respectively, to the beds above and below the unconformity first shown by Cross to exist in the Denver Basin. It has been and indeed to some extent still is the custom among vertebrate paleontologists to employ Laramie as a group term, applying it collectively to the beds containing the well-known ceratopsian fauna, such as the Arapahoe, Denver, and Lance. In the Canadian provinces Laramie is used practically as it was established by Dawson, Tyrrell, and others, namely, as a group term including the Edmonton (lower) and Paskapoo formations. The Edmonton is sometimes called "Lower Laramie," and the Paskapoo "Upper Laramie."

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[78] Science, new ser., vol. 42, p. 131, 1915.

[79] Bowen, C. F., The stratigraphy of the Montana group, with special reference to the position and age of the Judith River formation in north-central Montana: U. S. Geol. Survey Prof. Paper 90, pp. 95–153, 1915.

[80] Knowlton, F. H., Remarks on the fossil turtles accredited to the Judith River formation: Washington Acad. Sci. Proc., vol. 13, pp. 51–65, 1911.

[81] Stebinger, Eugene, The Montana group of northwestern Montana: U. S. Geol. Survey Prof. Paper 90, pp. 61–68, 1914.

[82] The stratigraphic position of the Bear River formation: Am. Jour. Sci., 3d ser., vol. 43, p. 98, 1892.

[83] On the Bear River formation, a series of strata hitherto known as the Bear River Laramie: Am. Jour. Sci., 3d ser., vol. 43, pp. 91–97, 1892; The Bear River formation and its characteristic fauna: U. S. Geol. Survey Bull. 128, 1895.

In the present work the usage established in the United States Geological Survey is followed. Laramie is considered as a formational term, and the Laramie formation is defined in accordance with the original definition of King, namely, as the uppermost member of the conformable Cretaceous series above the Fox Hills. This usage not only brings the term into harmony with the original application but places it in accord with most recent interpretation and obviates the confusion and looseness that must inevitably result from using it as a group term. If, as has been recently suggested, Laramie were to be employed as a group term it would involve the anomalous condition of embracing portions of two geologic systems which are separated by an unconformity that is believed by many to be one of the most important in the whole Rocky Mountain section. If a group term is needed for the several recognized formations containing the *Triceratops* fauna, it has already been supplied by Cross,[84] who has proposed for them the term Shoshone group, which is "defined as embracing the lacustrine, fluviatile, or terrestrial deposits, composed of detritus from the rising land area of the Rocky Mountain province, formed between the Laramie and Fort Union epochs."

IS THERE A TYPE SECTION FOR THE LARAMIE?

In the refinement of modern geologic methods it is considered essential that a type section be designated when a new formational or other stratigraphic unit is proposed, though it not infrequently happens that subsequent study discloses the fact that what was described as "typical" is a more or less incomplete expression of what the unit under consideration is found ultimately to represent. Concerning this point Ulrich[85] said:

> No local section contains within itself the data required for anything approaching a final classification of its component parts. This becomes possible only when exhaustive comparisons with many other near and far sections have been made. * * * The divisions are seldom drawn with due regard to the organic and diastrophic histories of the several beds.

At the time of the early work in the Rocky Mountain region, which resulted in the establishment of many of the stratigraphic units that have since become so widely known, appreciation was not so keen as to the necessity of tying such units to a definite type section, though even then the practice varied among the several geologists who were prominent in this field. The naming of the Laramie offers a case in point. It appears that it was the usual custom of King, who named and established the Laramie, to designate more or less definitely a type section or locality for each stratigraphic unit that he established. For the Laramie, however, he failed to do this specifically, though there was not then nor is there believed to be now any valid doubt as to just what he had in mind.

This state of affairs led Veatch[86] some years ago to make a critical historical study of various direct and collateral data which might be expected to afford some conclusion regarding what the term can and can not properly be used to designate. This study led Veatch to the conclusion that the Laramie Plains, and more specifically the vicinity of the town of Carbon, Wyo., should be considered as the type locality for the Laramie. He said:

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[84] Cross, Whitman, The Laramie formation and the Shoshone group: Washington Acad. Sci. Proc., vol. 11, pp. 27–45, 1909.

[85] Ulrich, E. O., Revision of the Paleozoic systems: Geol. Soc. America Bull., vol. 22, p. 387, 1911.

[86] Veatch, A. C., On the origin and definition of the geologic term "Laramie": Jour. Geology, vol. 15, pp. 526–549, 1907; abstract under same title in Am. Jour. Sci., 4th ser., vol. 24, pp. 18–22, 1907.

> The name "Laramie" is derived from the Laramie Plains, in eastern Wyoming. As commonly used in the early seventies, this included the plains region extending from the Front Range to and slightly beyond the North Platte River.
>
> The most important locality on the Laramie Plains at this time was Carbon. * * * It was the only locality on the Laramie Plains where the King Survey critically examined and distinctly delimited the Laramie beds.
>
> It was the practice of the King and Hayden surveys to name formations and groups from localities where the beds were regarded as typically exposed. While King and Hayden did not always definitely state that a name was derived from a certain locality, the source of the name can in all cases be completely inferred from the context.

Veatch then proceeded to argue that if the name was derived from the Laramie Plains, and if Carbon as the place best known at that time is taken as the type locality, it then follows that the term Laramie has been incorrectly applied for all these years, as it is now disclosed that only the beds above the great unconformity are exposed in that vicinity.

This question has been so thoroughly reviewed by Whitman Cross[87] in his paper on "The Laramie formation and the Shoshone group" that the following extended quotation is made:

> As to the origin of the term Laramie Mr. Veatch points out that Clarence King, who proposed the name and defined its application, was very careful in the choice of appropriate geographic formations. That is undoubtedly true in a general way; still King was not working under any such rule as that now prevailing in the United States Geological Survey. Much space is given to establishing by citations the exact application of the name Laramie Plains in the seventies, and to showing that sections of "Laramie" beds examined by the Hayden and King geologists were probably all above the unconformity seen at Carbon. * * * If the term Laramie had been in fact proposed especially for strata of the Laramie Plains, or even for a formation known by King and Hayden only in the zone traversed by the Union Pacific Railroad or the fortieth parallel in Wyoming, it is probable that many stratigraphers would agree with the sweeping conclusion that "strictly considered, the term Laramie, therefore, can appropriately be applied only to the beds above the great unconformity." * * * But the name was not so proposed. It was introduced into literature and defined by King as a compromise term for beds known to be widely distributed from Montana to New Mexico. The statement made by King is very clear as to the desire of Hayden and himself to have a name which each could use for a great series of supposedly conformable beds, without prejudice as to age. Laramie was practically proposed as a synonym for "Lignitic," but not as an exact one, for the term had been very broadly used by Hayden and others.
>
> There is not the slightest doubt as to the fundamental stratigraphic relations which King and Hayden thought characteristic of the Laramie. In all statements quoted and in others which might be cited the relation most strongly emphasized in regard to the Laramie is its conformity with the underlying Cretaceous beds. King believed the Laramie to be Cretaceous; Hayden thought it transitional between Cretaceous and Tertiary. King believed that Mesozoic sedimentation ended by reason of a great Rocky Mountain revolution and that the Laramie was separated from the lowest Eocene beds, erroneously supposed by him to be the Wasatch, by a marked unconformity. * * *
>
> The Laramie of King's conception was a natural stratigraphic unit with a well-defined base to be found in many places, but with an upper theoretical limit which might nowhere be represented, owing to the assumed pre-Tertiary erosion. It was to embrace the upper group of conformable Cretaceous sediments, deposited in brackish or fresh waters during gradual continental uplift.

The same ground was taken by A. C. Peale[88] in a paper published a few months after that by Cross. As Peale was a member of the Hayden Survey at the time the Laramie was established and was of course familiar with all the details connected with it, his testimony is especially valuable. Concerning a type locality for Laramie he said:

> There was no type locality so far as we [members of the Hayden Survey] were concerned, nor was there any such idea in the mind of Hayden. He proposed the name partly because it was a euphonious name and a broad one as he conceived it, the beds outcropping not only in the Laramie Plains but also on both sides of what was then sometimes known as the Laramie Range and also in the vicinity of the Laramie River. It was also proposed by him partly out of compliment to Clarence King, who was then working in what Hayden termed the Laramie Plains, he using the term in its very broadest sense as reaching from the Laramie Range to the Wasatch Range.[89] * * * It was intended that the name should cover all localities in which the beds occurred. If any localities should be considered as typical localities they would be those mapped by us along the Front Range in eastern Colorado and by King along the range in Wyoming. That Clarence King

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[87] Washington Acad. Sci. Proc., vol. 11, p. 29, 1909.

[88] On the application of the term Laramie: Am. Jour. Sci., 4th ser., vol. 28, pp. 45-58, 1909.

[89] Cf. Hayden, F. V., U. S. Geol. Survey Wyoming Rept., 1870, p. 121, 1871.

> had no type localities of the Laramie Plains in his mind is also evident from the fact that immediately following his definition of the Laramie he gives as localities of its occurrence the following in eastern Colorado, just north of the area in which the Hayden Survey was at work:
>
> Parks Station, Colo.
> 6 or 7 miles west of Carr's Station, Colo.
> West of Greeley, Colo.
> Crow Creek, Colo.
> Platteville, Colo.
>
> These were followed by references to "good exposures of Laramie" east of Separation and at other localities along the line of the Union Pacific Railroad in northwestern Colorado. It is interesting to note that Carbon, Wyo., does not appear in the list, and that Carr's Station is only about 24 miles east of the lower end of the Laramie Hills, while the other localities are within short distances of the east and southeast of the mountains.

Further quotations might be made from the writings of King and others in support of the contention above made by Cross and Peale, but they are hardly necessary, as it would seem to be established beyond reasonable question that no type section was named or intended for the Laramie, and it is still clearer that it was not intended to make Carbon and the Laramie Plains such a locality. It has been contended by some geologists that the original delimitation of the Arapahoe and Denver formations from the supposedly continuous Laramie section constituted a virtual redefinition of the Laramie, but this ground does not seem well taken, for the essential part of King's definition—namely, that it is the uppermost member of the conformable Cretaceous series above the Fox Hills—is maintained. This view was further emphasized by Cross,[90] who said:

> Although the Laramie was simple in its essential definition and conception, the strata referred to it included local deposits as well as those of wide distribution, and knowledge concerning some of these beds was very meager and untrustworthy when the group was established. It is a most natural result of detailed studies during the last 30 years that several formations at the top of the group assumed to have the relations embodied in King's definition have been found to possess other relations. But there is still a large formation answering to the fundamental part of King's definition, and to such beds it seems to me both natural and most expedient to apply the term Laramie in future. In the Laramie Plains there are, according to Veatch, 6,500 feet of conformable Cretaceous beds above the Montana strata and below the break at the base of the Carbon beds. The geographic term is thus still appropriate, even if the Carbon section be excluded from the Laramie. The term has now been so widely applied and for such a long time that it appears unwise to drop it, even if there should be proved to be no true Laramie beds on the Laramie Plains.

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[90] Cross, Whitman, The Laramie formation and the Shoshone group: Washington Acad. Sci. Proc., vol. 11, p. 31, 1909.

PART II. GEOLOGIC RELATIONS AND FLORA OF THE LARAMIE OF THE DENVER BASIN.

LITHOLOGIC AND STRATIGRAPHIC RELATIONS.

It is not my intention in the present connection to attempt a complete exposition of the lithology and stratigraphic relations of the Laramie in this area but simply to give enough of this history to serve as a setting for the paleobotanic data. One wishing to go thoroughly into this phase of the subject should consult the monograph on the geology of the Denver Basin,[91] from which much of the following brief account is condensed.

With the exception of a narrow belt along the foothills which is occupied by older formations, practically the entire Denver Basin is presumably underlain by the Laramie. As a surface formation it is confined chiefly to the northern portion of the basin and to a very narrow strip parallel with the foothills and at a distance from them of 1 or 2 miles. In this narrow belt the formation crops out in detached areas separated by overlapping deposits and extends from a point a few miles north of Denver to the vicinity of Colorado Springs. The beds are steeply tilted eastward along the foothills, but the dip becomes less toward the east, and in the central part of the basin, where the beds lie almost flat, the Laramie is covered by the Arapahoe, Denver, and Dawson formations.

The Laramie is the youngest Cretaceous formation in the Colorado Front Range region. It rests conformably on the Fox Hills sandstone, from which it is distinguished where in continuous outcrop by its lighter color and the presence in the topmost layer of the Fox Hills of numerous marine invertebrates.[92] In this area the Laramie was reported by the authors of the Denver Basin monograph to range in thickness between 600 and 1,200 feet, and Richardson, in the Castle Rock folio, reports a thickness of 1,200 feet in the foothill region to the south of Denver. Near Colorado Springs, the southernmost point at which the Laramie is recognized, the thickness is reduced to less than 400 feet.

According to Eldridge the Laramie is "divisible into two parts, a lower of sandstone and an upper composed of clay. The former has a uniform thickness of about 200 feet; the latter varies."[93]

In the lower division there are three persistent beds of sandstone, two of which occur at the base and have a thickness of approximately 60 feet, while the upper one has a thickness of 8 or 10 feet.

> The intervening ones not only disappear but vary in the horizon at which they occur. The coal beds also vary, one of several seams being workable at one locality and another in another.
>
> The sandstones are white and are composed almost exclusively of quartz, clear and opaque white. The material is somewhat loosely held together by cement, usually white but occasionally tinged brown by iron oxide.
>
> In the upper division the thickness, owing to uneven denudation from the top, varies between 400 and 1,000 feet. The strata are chiefly clays, through which are distributed small lenticular bodies of sandstone, innumerable concretionary ironstones from 2 to 4 feet in diameter, and narrow local seams of impure lignitic material. One or two beds of lignite are also present in its upper portion east of Denver.

The interpretation embodied in this quotation was generally accepted prior to 1915, and the coal formerly mined at Scranton, Colo., was believed to be in the upper division of the Laramie. In recent years certain fossil plants were collected near beds of coal which are supposed to be the same as the Scranton coals. These plants indicate Tertiary rather than Cretaceous age.

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[91] Emmons, S. F., Cross, Whitman, and Eldridge, G. H., U. S. Geol. Survey Mon. 27, 1896.

[92] It was stated by Eldridge that none of these invertebrates were known to pass into the Laramie, but according to Henderson (p. 87) at least two brackish-water species (*Ostrea glabra* and *Melania wyomingensis*) are now found to be common to the contiguous portions of both formations.

[93] This division into a lower and upper part has been interpreted by some as comparable to the use of "Lower Laramie" and "Upper Laramie" by Veatch in describing the section in Carbon County Wyo., but a careful reading of Eldridge's context shows clearly that no such separation was implied or intended. I am informed by Mr. Cross, the only surviving author of the Denver monograph, that these divisions were made simply to show that the lower part is made up prevailingly of sandstones and the upper part of clays. There is not the slightest known evidence of an unconformity between them, and no stratigraphic or formational importance is to be attached to this use of "lower" and "upper."

During the summer of 1915 W. T. Lee obtained evidence that the Scranton coal beds are in the Denver formation rather than in an upper division of the Laramie. He obtained the record of a well put down near Sable station, on the Union Pacific Railroad east of Denver and a few miles west of Scranton. This well is more than 3,000 feet deep and penetrated the Scranton coal beds, the Arapahoe conglomerate, the Laramie formation, the Fox Hills sandstone, and nearly 1,500 feet of the underlying shale. The record seems to establish the following relations:[94]

1. The coal beds of the so-called upper division of the Laramie occur in the Denver formation 200 to 450 feet above the top of the Laramie.
2. At this point the Arapahoe conglomerate is 50 feet thick.
3. The Laramie formation is here 700 feet thick with one thick bed of coal at the base.
4. The sandstone which underlies the Laramie coal and which presumably represents the so-called basal sandstone of the Laramie and the sandstone at the top of the Fox Hills is here only 160 feet thick.
5. Below this Fox Hills sandstone the upper part of the sandy fossiliferous shale may be of Fox Hills age, but there seems to be no way of distinguishing this part from the Pierre shale.

ANIMAL LIFE OF LARAMIE TIME IN THE DENVER BASIN.

VERTEBRATES.

If we are to judge from the remains that have thus far been brought to light, animal life of all kinds was exceedingly rare in the Denver Basin during Laramie time. So far as I know only a single fragment of a vertebrate has been reported from beds supposed to be of Laramie age within this area. The occurrence of this specimen was described as follows by G. H. Eldridge:[95]

> The vertebrate, according to Prof. Marsh, belongs to the order Ornithopoda of the subclass Dinosauria. The genus is undetermined. The specimen was found by a ranchman about 30 feet below the surface, in a well sunk through the upper Laramie strata, on the slopes of Dry Creek, about 8 miles southwest of the town of Brighton.

This locality is apparently about 10 miles due north of Denver and according to the geologic map accompanying the Denver Basin monograph should fall within an area indicated as Laramie. The beds were thought by Eldridge to represent the upper part of the Laramie, but in the light of the results obtained by Lee (p. 103) only a few miles east of this Dry Creek locality, it seems more than probable that this supposed upper Laramie belongs to the Denver formation, in which case the bone came either from the Denver or the Arapahoe. A depth of only 30 feet below the surface would certainly not reach the Laramie and would probably place it in the Arapahoe, which is well known to contain vertebrate remains. Thus, to the uncertainty of the biologic interpretation of this fragment is added the indefiniteness of its stratigraphic position, and it can be dismissed as absolutely without value.

INVERTEBRATES.

The only remains of invertebrates recorded from the Laramie of the Denver Basin by Eldridge[96] are *Ostrea glabra* and *Unio* sp.?, determined by C. A. White. Eldridge said: "The occurrence of *Ostrea glabra* is general for the field and always at the same horizon, a short distance above the basal sandstones of the formation."

Beds held to be of true Laramie age have been found in the valley of Crow Creek, which is about 25 miles east of Greeley and between 40 and 50 miles north a little east of Denver, outside the strict limits of the Denver Basin as accepted in the Denver monograph. This region was visited by C. A. White[97] in 1877, while he was attached to the Hayden Survey.

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[94] In a personal communication Lee states that the written log of the upper part of this well to a depth of 1,300 feet could not be obtained, but that the record of the beds below this depth is copied from the driller's notes. The upper part of the record is based on the independently procured statements of the driller and two other men who were sufficiently interested to keep themselves constantly informed of the progress of the well. The testimony of these three men agreed in all essential points. They were questioned particularly in reference to the Scranton coals and the conglomerate. The position of the beds of coal can not be reasonably doubted, as they crop out east of the well and are reported from numerous water wells in the vicinity of Sable. The conglomerate was described as consisting of pebbles of "quartz, flint, black diamonds," etc., the largest an inch or more in diameter. Some of the pebbles described as "black diamonds" had been preserved and appear to consist of black chert. In response to a query as to the number of the pebbles the statement was made that "bushels of them came out." Lee afterward visited the locality near Morrison where these beds crop out and found that the driller's description corresponded very closely with the beds as they are exposed at the surface. All things considered, the log seems to be as well authenticated as the average driller's record.

[95] U. S. Geol. Survey Mon. 27, p. 77, 1896.

[96] Op. cit., p. 78.

[97] Report on paleontological field work for the season of 1877: U. S. Geol. and Geog. Survey Terr. Eleventh Ann. Rept., pp. 163-173, 1879.

He wrote as follows concerning the stratigraphy and paleontology:

In this valley, as in all the plains region round about, the exposures of strata are not only few, but none of them are extensive. The most southerly exposure is about 10 miles from the mouth of the creek, and here I again recognized the oyster horizon, which has been mentioned twice before. The species mentioned before were found abundantly here, and many other molluscan species besides, in associated layers. I traced this fossiliferous horizon northward for a distance of 5 or 6 miles above the point where I first discovered it and found it to occupy nearly a uniform height above the level of the creek. The exposures are in the face of the low sloping hills that border the east side of the valley and are distant from the creek only from a few hundred feet to half a mile.

The full section of the strata constituting the valley side here was quite clearly ascertained, although the débris which prevails upon the plains has so obscured them in most places, even on the slope, that they were not all observable at any one point. The following is a record of the section as ascertained by measurements at several different points within the few miles that they were found exposed, as before stated:

Crow Creek section.

		Feet.
1.	Sandy soil or débris of the plains	10
2.	Grayish siliceous marl	5
3.	Sandy and calcareous layers; with *Corbula*, etc	3
4.	Soft sandy and argillaceous material; with *Ostrea* and *Anomia*	5
5.	Arenaceous rock, somewhat concretionary; with numerous fresh-water forms	2
6.	Arenaceous marly strata	20
7.	Carbonaceous shale	6
8.	Gray siliceous marl	6
9.	Carbonaceous shale	3
10.	Gray siliceous marl	25
11.	Unexposed to the surface of the creek	5

No. 1 is the prevailing débris of the plains, which at top constitutes the sandy soil.

No fossils were found in No. 2, but it is evidently a part of a continuous deposit with those beneath. * * *

The following is a list of the fossils obtained from the different members of this section:

List of fossils from the valley of Crow Creek, Colo.

1. Anomia micronema Meek.
2. Anomia gryphorhynchus Meek.
3. Ostrea glabra Meek and Hayden.
4. Volsella (Brachydontes) regularis White.
5. Anodonta parallela White.
6. Unio ———?
7. Corbicula cleburni White.
8. Corbicula obesa White.
9. Corbicula cardiniaeformis White.
10. Corbicula (Leptesthes) subelliptica Meek and Hayden.
11. Corbicula (Leptesthes) fracta Meek.
12. Corbicula (Leptesthes) macropistha White.

List of fossils from the valley of Crow Creek, Colo.—Contd.

13. Corbicula (Leptesthes) planumbona Meek
14. Corbula subtrigonalis Meek and Hayden.
15. Bulinus disjunctus White.
16. Bulinus subelongatus Meek and Hayden.
17. Physa felix White.
18. Goniobasis gracilienta Meek and Hayden.
19. Goniobasis nebrascensis Meek and Hayden.
20. Melania wyomingensis Meek.
21. Viviparus prudentia White.
22. Tulotoma thompsoni White.
23. Campeloma multistriata Meek and Hayden.
24. Corydalites fecundum Scudder.

* * * * * * *

At a point about 18 miles east of Greeley I found the uppermost strata of the Fox Hills group in the south valley side of South Platte River, and from that point to about 6 miles farther eastward I continued to see small exposures of the same, most of which were obscure. I however recognized about 20 feet in thickness of strata, and the fossils, which were few and imperfect, were quite sufficient to indicate an exact equivalency of the strata containing them with those of the upper part of the section at the mouth of the St. Vrains. Besides these few characteristic invertebrate fossils, I also found fragments of the fucoid *Halymenites major* in one of the upper layers. The known general dip of the strata of all that region makes it practically certain that the Cretaceous strata pass beneath the level of the streams along a northward and southward line which may be drawn a couple of miles west of Greeley; that they receive a greater or less thickness of Laramie strata upon them beneath the débris of the plains. Then a gentle rise brings them up again to view in the valley of South Platte River, from 18 to 25 miles east of Greeley, as already mentioned. They seem then to pass again by a gentle easterly dip beneath the surface of the river, but I did not trace them farther, as my journey led up the valley of Bijou Creek. It is probable, however, that the exposures of these uppermost of the Fox Hills strata continue at the surface farther down the South Platte, in its immediate valley. Between Greeley and the point where these Cretaceous strata are exposed the space is no doubt occupied by at least a small portion of the strata of the Laramie group, which are covered with the débris of the plains, but I found no exposures of Laramie strata until I reached the valley of Bijou Creek, about 12 miles above its mouth. * * *

From the valley of Bijou Creek my investigations led me southwestward to Cherry Creek Plateau, during which I passed over the higher strata of the Laramie group, which come in the series between those that I found exposed near Bijou Station and the sandstones of the Monument Creek group that constitute the plateau. I found no fossils of any kind in these higher Laramie strata except silicified wood, which in some places was quite plentiful. It is possible that certain layers in this portion of the Laramie group contain invertebrate fossils, but the whole series in this region above the horizon of the fossiliferous layers of the Crow Creek and Bijou Creek sections is apparently destitute of invertebrate remains.

The whole thickness of Laramie strata which I thus passed over, from the uppermost layers of the Fox Hills group in the valley of South Platte River to the base of the Monument Creek group on Cherry Creek Plateau, is estimated at about 1,800 feet. So far as I could discover, only about the lower 200 or 250 feet of this series is known to contain invertebrate fossils; and the lower 700 or 800 feet appears also to contain all the coal of the Laramie group in this region.

This area was visited by T. W. Stanton and me in 1896,[98] and the thickest section found showed the invertebrates and plants through a distance of only 40 or 50 feet. The beds underlying the Laramie were at no place disclosed.

In this connection inquiry was made of Prof. Junius Henderson, of the University of Colorado, who is known to have an extensive knowledge of the geology of northeastern Colorado. In a letter to me Prof. Henderson states that after a very thorough exploration of this region he has not been able to fix the thickness of the Laramie section in this area with any degree of positiveness. He says: "On the whole I have no evidence that would show more than 100 feet of Laramie around Crow Creek, but my impression is that it is a little more."

It appears to have been thought by those who had previously visited this area that there was probably a considerable thickness of Laramie beds both beneath and above the Crow Creek exposures and, further, that these exposures should hold a position relatively high in the full Laramie section, as would naturally be inferred from their location far out on the plains and away from the mountains against which the Laramie is so steeply upturned. This view also finds some confirmation in the fact that only one of the species of invertebrates (*Ostrea glabra*) common on Crow Creek is known to occur in the Laramie of the Denver Basin. This was the view at first entertained by Prof. Henderson, but he states that his faith in the high position of the deposits on Crow Creek was shaken by the "finding of Fox Hills strata in geographically high positions on the divides and in the ravines far out from the mountains and in some instances unquestionably not far below fossiliferous beds of the Laramie."

Continuing, he says:

> In the irregular cross-bedded sandstone on top of Wildcat Mound northwest of Platteville, within 40 feet of the Fox Hills sandstone, I found a thick bed containing great quantities of *Ostrea glabra*, with a few specimens which I have identified as *Corbicula cleburni* White, *C. fracta* Meek, *C. micropistha* White, and *Anomia micronema*. They were not very well preserved, but certainly they are correctly determined generically and I believe also specifically. The shales intervening between this stratum and the topmost sandstone of the Fox Hills is doubtless the same as that found between the Fox Hills and the coal beds at Windsor and elsewhere, but I have never been able to find any determinative fossils or ascertain whether or not it is marine. At Wildcat Mound *Halymenites major* occurs in both the marine and the *Corbicula* beds.
>
> Going northward from Wildcat Mound to Milliken the upper Fox Hills sandstone thins out very much and is overlain by shales. From 100 to 150 feet up in the shale is a coal vein, but no fossils were found in this shale.
>
> I also failed to find the *Ostrea-Corbicula* sandstone at Windsor, where the exposure of the strata overlying the uppermost sandstone of the Fox Hills is almost complete for a long distance, or at Indian Spring mine, north of Wellington, where such a sandstone if present would show in the slope between this sandstone and the coal.
>
> Throughout the Crow Creek district, eastward to Wildcat Creek and Cottonwood Spring, I always found Corbiculas, etc., in contact with or beneath the lowest coal. On the divide some miles east of Crow Creek, near Greasewood Lake, southeast of Osgood post office, I found Fox Hills strata yielding *Lunatia*, *Tellina*, *Cardium*, *Dentalium*, *Mactra*, *Nucula*, *Baroda*, and *Halymenites*. Almost anywhere to the east, west, northeast, and north of Osgood *Ostrea glabra* and various species of *Corbicula* may be found, with coal seams, some of the fossiliferous beds being surely not many feet above the marine Fox Hills strata just mentioned.
>
> At Cottonwood Springs, some 15 miles northeast of Orchard, I found a 4-foot bed of shale containing *Ostrea glabra*, *Anomia micronema*, *Corbicula cleburni*, *C. fracta*, *Corbula subtrigonalis*, and *Melania wyomingensis*. Thirty feet of shales immediately underlying this bed yielded *Nucula*, *Baroda*, *Cardium speciosum*, and *Turritella?*
>
> I found Fox Hills strata again well up the west valley slope of Wildcat Creek, north of Fort Morgan. There I found *Vaniella humilis* and *Pholadomya subventricosa*, which usually are found at the base of and below the uppermost Fox Hills sandstone, together with *Tellina scitula* and *Lucina* sp. I found Fox Hills marine fossils in the bluffs and slopes of the South Platte Valley as far out as Canton, Weldon, and Messex.
>
> From all the evidence now at hand I can not see how the lowest fossil horizon at Crow Creek can be, at most, more than 50 to 100 feet above the Fox Hills marine strata.

A critical analysis of the geographic and stratigraphic range of these Crow Creek invertebrates would be of considerable interest, but this is outside of my knowledge or the scope of the present report. I may simply note in passing that it appears to have been demonstrated that certain of the species present at Crow Creek have a very considerable vertical range, occurring in the Claggett and Judith River formations of Montana, the Belly River of Canada, the "Lower Laramie" of Carbon County, Wyo., the "Laramie" of Black Buttes, Wyo., the Mesaverde of Routt County, Colo., and of the Grand Mesa of northwestern Colorado, the Montana of the San Juan Basin, and other formations. Prof. Henderson, in the letter above mentioned, has the following to say regarding two of the species:

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[98] Stanton, T. W., and Knowlton, F. H., Stratigraphy and paleontology of the Laramie and related formations in Wyoming: Geol. Soc. America Bull., vol. 8, p. 151, 1897.

> One of the most abundant fossils on the east side of Crow Creek valley and thence well out on the divide to the east for miles is *Ostrea glabra*, which is also abundant in the Boulder district and in many places occurs in the Fox Hills beds as well as low in the Laramie. *Melania wyomingensis* also occurs 4 miles east of Boulder, in marine Fox Hills strata, though smaller than the exceedingly large specimens on the east side of Crow Creek.

AMBER IN THE LARAMIE OF THE DENVER BASIN.

Amber in minute quantities has long been known to be rather widely distributed in certain Upper Cretaceous strata of the eastern United States,[99] but so far as known to me it appears to be of extremely rare occurrence in other parts of North America. A small quantity from the Laramie at Marshall, Boulder County, Colo., has recently been reported by T. D. A. Cockerell.[1] Concerning it he wrote as follows:

> This locality produces much of the coal used in Boulder and has long been known to paleobotanists, having furnished important materials to Lesquereux many years ago. Perhaps the most interesting thing found was a small piece of amber embedded in the solid rock. It measures about 8 millimeters by 5.5 millimeters and is translucent orange-brown, darker than Baltic amber. It is practically insoluble in alcohol; a small fragment left in it over night was scarcely if at all diminished. In ether it eventually becomes opaque and friable.

In a footnote Cockerell states that "since the above was written we have found quantities of amber in the coal at Marshall. None of the pieces is of large size." The amber was searched for included insects, but so far without success.

The well-known Baltic or typical amber is the product of a coniferous tree, but coniferous remains are of extremely rare occurrence in the plant beds at Marshall, and it is quite impossible with the data at present available to ascertain the plant that produced the amber found there. As Cockrell stated, "Judging from the accompanying foliage, it is very probably not even the product of a conifer."

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[99] Hollick, Arthur, The occurrence and origin of amber in the eastern United States: Am. Naturalist, vol. 39, p. 137, 1905. Berry, E. W., Coastal Plain amber: Torreya, vol. 7, p. 4, 1907. Knowlton, F. H., An American amber-producing tree: Science, new ser., vol. 3, p. 582, 1896.

[1] Amber in the Laramie Cretaceous: Torreya, vol. 9, p. 140, 1909.

PART III. THE LARAMIE FLORA.

BIBLIOGRAPHY OF PAPERS RELATING TO THE LARAMIE FLORA IN THE DENVER BASIN.

1868.

Lesquereux, Leo, in Le Conte, J. L., Notes on the geology of the survey for the extension of the Union Pacific Railway, E. D., from the Smoky Hill River, Kansas, to the Rio Grande, pp. 47-53, Philadelphia, 1868.

Lesquereux, Leo, [Notes on fossil plants from lignite deposits of the West]: Am. Jour. Sci., 2d ser., vol. 45, pp. 198-204, 1868; copied without change in Hayden, F. V., U. S. Geol. and Geog. Survey Terr. [Third] Ann. Rept., p. 96, 1869; reprint, p. 196, 1873.

1873.

Lesquereux, Leo, Lignitic formation and fossil flora: U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1872, pp. 317-427, 1873. [See pp. 382-384 for description of plants from Marshall and Erie.]

1878.

Lesquereux, Leo, The Tertiary flora: U. S. Geol. Survey Terr. Rept., vol. 7, pp. 1-366, pls. 1-45, 1878.

Lesquereux, Leo, Catalogue of the Cretaceous and Tertiary plants of North America, with references to their descriptions: U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1876, pp. 487-520, 1878.

1883.

Lesquereux, Leo, The Cretaceous and Tertiary floras: U. S. Geol. Survey Terr. Rept., vol. 8, pp. 109-126, 1883.

1886.

Ward, L. F., Synopsis of the flora of the Laramie group: U. S. Geol. Survey Sixth Ann. Rept., for 1884-85, pp. 399-557, pls. 31-65, 1886.

1887.

Ward, L. F., Types of the Laramie flora: U. S. Geol. Survey Bull. 37, pp. 1-354, pls. 1-57, 1887.

1896.

Knowlton, F. H., in Emmons, S. F., Cross, Whitman, and Eldridge, G. H., Geology of the Denver Basin in Colorado: U. S. Geol. Survey Mon. 27, pp. 466-473, 1896.

1898.

Knowlton, F. H., Catalogue of the Cretaceous and Tertiary plants of North America: U. S. Geol. Survey Bull. 152, pp. 1-247, 1898.

1909.

Cockerell, T. D. A., Amber in the Laramie Cretaceous: Torreya, vol. 9, pp. 140-143, 1909.

1915.

Knowlton, F. H., in Richardson, G. B., U. S. Geol. Survey Geol. Atlas, Castle Rock folio (No. 198), p.7, 1915.

1919.

Knowlton, F. H., A catalogue of the Mesozoic and Cenozoic plants of North America: U. S. Geol. Survey Bull. 696, 815 pp., 1919.

LOCAL DISTRIBUTION OF THE FLORA.

Before proceeding to the discussion of the geologic, biologic, and ecologic relations of the Laramie flora comprised in the present work, it may be of some interest to enumerate the several localities together with the forms found at each place. The first Laramie plants made known to science were named and described by Leo Lesquereux.[2] They are given in the first of the following lists.

Marshall's mine, Marshall, Boulder County, Colo.:
- Lygodium compactum Lesquereux.
- Juglans rugosa Lesquereux.
- Quercus chlorophylla Unger.
- Quercus lyelli Heer.
- Cinnamomum affine Lesquereux.
- Acer, fruit of.
- Acer, leaves of.
- Rhamnus salicifolius Lesquereux.
- Cornus incompletus Lesquereux.
- Echitonium sophiae.
- Phyllites sulcatum Lesquereux.

Marshall's mine, Marshall, Colo.; collected by N. L. Britton for J. S. Newberry, about 1884:
- Sequoia acuminata? Lesquereux.
- Carpites marshallensis Knowlton, n. sp.
- Juglans praerugosa Knowlton, n. sp.
- Ficus coloradensis Cockerell.
- Ficus navicularis Cockerell.
- Ficus planicostata Lesquereux.
- Cinnamomum affine Lesquereux.
- Aristolochia brittoni Knowlton, n. sp.
- Dombeyopsis ovata Knowlton, n. sp.
- Phyllites marshallensis Knowlton, n. sp.

Railway cut between old and new stations, Marshall, Colo.; collected by A. C. Peale, 1908:
- Hicoria angulata Knowlton, n. sp.
- Hicoria minutula Knowlton, n. sp.
- Ficus impressa Knowlton, n. sp.
- Rhamnus salicifolius Lesquereux.
- Zizyphus minimus Knowlton, n. sp.
- Mimosites marshallensis Knowlton, n. sp.
- Dombeyopsis obtusa Lesquereux.

Dump of old Marshall mine, Marshall, Colo.; collected by A. C. Peale, 1908:
- Ficus impressa? Knowlton.

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[2] [Notes on fossil plants from Rock Creek, etc.]: Am. Jour. Sci., 2d ser., vol. 46, p. 208, 1868; copied in Hayden, F. V., U. S. Geol. Survey Terr. [Third] Ann. Rept., p. 96, 1869 [reprint, p. 196, 1873.]

Dump of mine at west end of wooded bluff just south of Marshall, Colo.; collected by A. C. Peale, 1908:

Ficus arenacea Lesquereux.
Ficus impressa? Knowlton.
Dombeyopsis obtusa Lesquereux.

Marshall, Colo., railway cut at junction of Eldorado Springs branch of Colorado Southern Railroad:

Cyperacites, fragment.
Rhamnus salicifolius Lesquereux.

Marshall, Colo., west of wooded bluff just south of the town and above coal in an old opening; collected by A. C. Peale, 1908:

Ficus cockerelli Knowlton, n. sp.
Ficus coloradensis? Cockerell.
Cinnamomum affine Lesquereux.
Palm, gen. and sp.?

Marshall, Colo., half a mile south of railway station and in first draw north of white sandstone bluff, just above highest coal of the region; collected by F. H. Knowlton, 1908:

Sequoia longifolia Lesquereux.
Ficus coloradensis? Cockerell.
Ficus planicostata magnifolia n. var.
Ficus? impressa Knowlton, n. sp.
Artocarpus lessigii (Lesquereux) Knowlton.
Cassia laramiensis Knowlton, n. sp.

Marshall, Colo., wooded bluff just south of the town; collected by A. C. Peale, 1908:

Pteris? sp.
Dammara sp.
Cyperacites sp.
Salix wyomingensis Knowlton and Cockerell.
Ficus navicularis Cockerell.
Cinnamomum affine Lesquereux.
Malapoenna louisvillensis Knowlton, n. sp.
Rhamnus salicifolius Lesquereux.
Rhamnus marshallensis Knowlton, n. sp.
Rhamnus goldianus? Lesquereux.
Leguminosites? coloradensis Knowlton, n. sp.

Dump of mine at Erie, Colo.; collected by N. L. Britton for J. S. Newberry about 1884. This mine has long been abandoned, and when I visited it in 1908, I could not obtain even a scrap of a plant:

Anemia.
Ficus sp.?
Juglans newberryi Knowlton, n. sp.
Quercus eriensis Knowlton, n. sp.
Nelumbo tenuifolia (Lesquereux) Knowlton, n. comb.
Dombeyopsis? sinuata Knowlton, n. sp.
Dombeyopsis ovata Knowlton n. sp.
Dombeyopsis obtusa Lesquereux.
Ceanothus eriensis Knowlton, n. sp.
Rhamnus brittoni Knowlton, n. sp.
Rhamnus minutus Knowlton, n. sp.
Rhamnus salicifolius Lesquereux.
Celastrinites alatus Knowlton, n. sp.
Celastrinites eriensis Knowlton, n. sp.
Pistacia eriensis Knowlton, n. sp.
Pistacia hollicki Knowlton, n. sp.
Ilex laramiense Knowlton, n. sp.
Leguminosites columbianus Knowlton, n. sp.
Hedera lucens Knowlton, n. sp.

1¾ miles northeast of Erie, Colo.; collected by F. H. Knowlton and G. C. Martin, 1908:

Asplenium martini Knowlton, n. sp.

Railway cut near Superior, Colo.; collected by A. C. Peale, 1908:

Rhamnus salicifolius Lesquereux.

Dump of Rex mine No. 11, Louisville, Colo.; collected by A. C. Peale, 1908:

Sequoia longifolia Lesquereux.
Cyperacites sp.
Cinnamomum affine Lesquereux.
Malapoenna louisvillensis Knowlton, n. sp.
Ficus sp.
Zizyphus or Ceanothus sp., fragment of base.

Dump of Simpson mine, Lafayette, Colo.; collected by A. C. Peale, 1908:

Phanerophlebites pealei Knowlton, n. sp.
Sapindus-like fragment.

Coal Creek, Boulder County, Colo.; collected by N. L. Britton for J. S. Newberry about 1884:

Salix brittoniana Knowlton, n. sp.
Salix wyomingensis Knowlton and Cockerell.
Juglans laramiensis Knowlton, n. sp.
Ficus arenacea Lesquereux.
Ficus planicostata Lesquereux.
Ficus praeplanicostata Knowlton, n. sp.
Artocarpus liriodendroides Knowlton, n. sp.
Dombeyopsis obtusa Lesquereux.
Aristolochia brittoni Knowlton, n. sp.
Phyllites trinervis Knowlton, n. sp.

Murphy coal mine, on Ralston Creek, 5½ miles north of Golden, Colo.; collected by A. C. Peale, 1908:

Palm, gen. and sp.?
Ficus cockerelli Knowlton, n. sp.
Ficus navicularis? Cockerell.

Murphy coal bank, Ralston Creek, north of Golden, Colo.; collected by Arthur Lakes, 1890:

Carpites lakesii Knowlton, n. sp.
Palaeoaster similis Knowlton, n. sp.

Hoyt's coal mine, 1 mile south of Golden, Colo.; collected by Arthur Lakes, 1890:

Sabal montana Knowlton.
Phragmites sp.
Ficus arenacea Lesquereux.
Ficus cockerelli Knowlton, n. sp.
Ficus navicularis Cockerell.
Dombeyopsis obtusa Lesquereux.

Leyden Gulch, east of road to Boulder and 6½ miles north of Golden, Colo.; collected by A. C. Peale, 1908:

Cyperacites sp.
Cyperacites? sp.
Sabal montana Knowlton.
Juglans leydenianus Knowlton, n. sp.
Ficus cockerelli Knowlton, n. name.
Ficus navicularis Cockerell.
Ficus? leyden Knowlton, n. sp.
Cinnamomum affine Lesquereux.
Dombeyopsis sp. cf. D. trivialis Lesquereux.
Apeibopsis? laramiensis Knowlton, n. sp.
Phyllites leydenianus Knowlton, n. sp.
Apocynophyllum taenifolium Knowlton, n. sp.

Cut on Moffat railroad (Denver & Salt Lake) at crossing of road to Boulder, about 8 miles north of Golden, Colo.; collected by A. C. Peale, 1908:

Sequoia acuminata? Lesquereux.
Cyperacites sp.
Palm, gen. and sp.?
Juglans praerugosa Knowlton, n. sp.
Salix myricoides Knowlton, n. sp.
Ficus arenacea Lesquereux.
Ficus cockerelli? Knowlton, n. name.
Ficus neodalmatica Knowlton, n. sp.
Ficus navicularis Cockerell.
Ficus planicostata Lesquereux.
Cinnamomum affine Lesquereux.
Rhamnus? pealei Knowlton, n. sp.
Rhamnus salicifolius Lesquereux.
Phyllites sp.

1¼ miles west of Golden, Colo.; collected in 1881 by Lester F. Ward. A hard white sandstone showing the following forms:

Sabal montana? Knowlton.
Ficus crossii Ward.
Ficus arenacea Lesquereux.
Ficus cockerelli Knowlton, n. name.
Ficus navicularis Lesquereux.
Ficus planicostata Lesquereux.
Salix wyomingensis Knowlton and Cockerell.
Platanus platanoides (Lesquereux) Knowlton.

Half a mile west of Golden, Colo.; collected by Lester F. Ward, 1881:

Sabal montana? Knowlton, fragment only.

About 2 miles south of Golden, Colo,; collected by A. C. Peale, 1908:

Juglans praerugosa Knowlton, n. sp.
Platanus platanoides (Lesquereux) Knowlton.
Rhamnus salicifolius Lesquereux.

About 3 miles south of Golden, Colo.; collected by A. C. Peale, 1908:

Ficus navicularis Cockerell.

1½ miles south of Golden, Colo.; collected by A. C. Peale, 1908:

Ficus cockerelli Knowlton, n. name.
Ficus sp.
Zizyphus hendersoni Knowlton, n. sp.

Mount Carbon, Morrison, Colo.; collected by Arthur Lakes, 1890:

Dryopteris carbonensis Knowlton, n. sp.
Sequoia acuminata Lesquereux.
Phragmites sp.
Salix wyomingensis Knowlton and Cockerell.
Hicoria angulata Knowlton, n. sp.
Artocarpus lessigiana (Lesquereux) Knowlton.
Ficus? smithsoniana (Lesquereux) Lesquereux.
Ficus navicularis Cockerell.
Cinnamomum laramiense Knowlton, n. sp.
Rhamnus salicifolius Lesquereux.
Ceanothus ovatifolius Knowlton, n. sp.

Mount Carbon, Morrison, Colo.; collected by Arthur Lakes, 1890:

Phragmites sp.
Sequoia acuminata Lesquereux.

Cowan Station, south of Denver, Colo.; collected by F. H. Knowlton and A. C. Peale, 1908:

Ficus cowanensis Knowlton, n. sp.
Dombeyopsis obtusa Lesquereux.
Cornus praeimpressa Knowlton, n. sp.
Celastrinites sp.
Salix wyomingensis Knowlton and Cockerell.
Cinnamomum affine Lesquereux.
Populus? distorta Knowlton, n. sp.
Phyllites.
Zizyphus regularis Knowlton, n. sp.
Artocarpus lessigiana (Lesquereux) Knowlton.
Ficus pealei Knowlton, n. sp.
Anona coloradensis Knowlton, n. sp.
Cinnamomum laramiense Knowlton, n. sp.
Cornus sp.
Cyperacites sp.
Ficus apiculatus Knowlton, n. sp.
Rhamnus salicifolius Lesquereux.
Ficus praetenuinervis? Knowlton.
Palm, Sabalites sp.?

Old Franceville mine, 12 miles southeast of Colorado Springs, Colo.; obtained by A. C. Peale,[3] 1873, and identified by Lesquereux:

Sabal campbelli? Newberry=Sabal montana Knowlton?
Smilax grandifolia? Unger=Smilax? inquirenda?
Quercus sp.=?
Ficus spectabilis Lesquereux=Ficus denveriana?
Rhamnus cleburni Lesquereux=Rhamnus sp.
Paliurus sp.=Zizyphus coloradensis?

Near Old Franceville mine, 12 miles southeast of Colorado Springs, Colo., from sandstone overlying the main (lowest) coal, in south bank of creek 200 feet north of high-road bridge, near west line of sec. 19, T. 14 S., R. 64 W.; collected by A. C. Peale and M. I. Goldman, 1908 [No. 19]:

Cyperacites sp., fragments.
Myrica torreyi Lesquereux.
Ficus arenacea Lesquereux.
Ficus navicularis Cockerell.

Old Franceville mine, 12 miles southeast of Colorado Springs, Colo. [NW. ¼ sec. 24, T. 14 S., R. 65 W.]; collected by A. C. Peale and M. I. Goldman, 1908 [No. 18]. This is the same locality as that at which Peale made his collection in 1873, but as the mine has long been abandoned, only the following fragments could be identified:

Cinnamomum affine Lesquereux.
Ficus sp.?
Cissus? sp. (base only preserved).

Gehrung's coal mine, Popes Bluff, west of Pikeview, Colo.; collected by Leo Lesquereux,[4] 1872:

Sabal campbelli? Newberry=Sabal montana? Knowlton.
Platanus haydenii Newberry.
Ficus tiliaefolia (Al. Braun)=Ficus cockerelli?
Dombeyopsis obtusa Lesquereux=Dombeyopsis obtusa.

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[3] South Park division [Colo.]: U. S. Geol. and Geog. Survey Terr. Rept. for 1873, pp. 203, 393, 1874.

[4] Lignitic formation and fossil flora: U. S. Geol. and Geog. Survey Terr. Rept. for 1872, pp. 326, 375, 1873.

Popes Bluff, west of Pikeview, Colo.; collected by A. C. Peale and M. I. Goldman, 1908:

Pteris goldmani Knowlton, n. sp.
Cyperacites? tessellata Knowlton, n. sp.
Sabal sp. cf. S. montana Knowlton?
Smilax? inquirenda Knowlton, n. sp.
Juglans praerugosa Knowlton, n. sp.
Juglans laramiensis Knowlton, n. sp.
Myrica dubia Knowlton, n.sp.
Ficus arenacea Lesquereux.
Ficus denveriana? Cockerell.
Ficus cockerelli Knowlton, n. name.
Ficus navicularis Cockerell.
Ficus planicostata Lesquereux.
Cinnamomum affine Lesquereux.
Rhamnus salicifolius Lesquereux.
Rhamnus sp.
Zizyphus coloradensis Knowlton, n. sp.
Dombeyopsis obtusa Lesquereux.

Opposite sand-lime brick works, Pikeview, 4 miles north of Colorado Springs, Colo.; collected by A. C. Peale, 1908 [No. 24]:

Anemia sp.
Ficus arenacea? Lesquereux.
Ficus navicularis Lesquereux.
Ficus sp.
Cinnamomum affine? Lesquereux.
Rhamus salicifolius Lesquereux.
Dombeyopsis trivialis? Lesquereux.
Leguminosites laramiensis Knowlton, n. sp.

Crow Creek, about 25 miles northeast of Greeley, Colo.; collected by F. H. Knowlton and T. W. Stanton, 1896:

Sequoia acuminata Lesquereux.
Myrica torreyi Lesquereux.
Platanus platanoides? (Lesquereux) Knowlton.
Dombeyopsis obtusa Lesquereux.

DIFFICULTIES IN THE STUDY OF THE EARLIER COLLECTIONS.

Much difficulty has been experienced in studying the older collections from this region. For many years it was not supposed to be necessary to give more than a very general locality label—such as "Golden, Colo.," "near Denver, Colo.," as it was presumed that all the plant-bearing beds were of the same age. At first the age was given as "Lignitic" or "Colorado Lignitic," and later all the specimens were referred to the Laramie without distinction. However, when it was later demonstrated that two or even three distinct plant-bearing formational units may be present in the same section, confusion became confounded. It was the fusion of horizons, here and elsewhere, that for so long a time obscured and negatived any results that could be obtained by a study of the flora. Consequently, after the segregation of the Arapahoe and Denver formations from the Laramie, it naturally became of the greatest interest and importance to ascertain the extent to which the fossil flora confirmed this differentiation of horizons.

In the absence of original labels or other data by which the plants can be connected with a definite locality or horizon, there appear to be only two methods by which their position can be arrived at—(1) by a study of the lithologic characteristics of the matrix containing the fossils, or (2) by the collection of additional specimens from beds of known position. When Whitman Cross [5] established the Denver formation he recognized at once the necessity for making an examination of this kind, and consequently he made a careful study of the matrix of such of the Golden plants as were then available. Fortunately, nearly 90 per cent of the specimens on which Lesquereux based his work are preserved in the collections of the United States National Museum, and by studying the matrix of each species Cross was able to arrive at valuable results. As is now known, it is comparatively easy to distinguish between the quartzose sandstone of the Laramie and the peculiar yellowish-brown andesitic material of the Denver.

This study by Cross was confined to the plants from Golden enumerated by Lesquereux in his "Tertiary flora" and "Cretaceous and Tertiary floras." These works together describe just 100 species from this locality, hence numbers express percentages. Cross was then able to find 79 species, of which he says:

> Eighteen occur in what is judged to be Laramie sandstone or shale, and 59 in distinct Denver beds of Table Mountain, while 7 occur in both rocks, and 9 cases are in doubt. Lesquereux gives horizons for 6 species that were not found. By combining these two sources of information we get probable indications for 76 per cent of the Golden fossil plants; 22 per cent came from true Laramie strata and 63 per cent from Table Mountain beds; 9 per cent occur in both formations.

A few years later Lesquereux [6] published a short paper entitled "Fossil plants collected at Golden, Colo.," in which he added 60 species to this flora. There is no mention in this paper of a definite horizon or of an exact locality for a single species beyond the statement that they were collected at Golden and came from the Laramie. It was ascertained later from Arthur Lakes, who collected this material, that so far as he could recall all came from Table Mountain or Green Mountain, and that "none of them came from the proximity of the lower coal measures." This material is the property of Harvard University and has not been reviewed in the present connection, but I saw it casually some years ago and do not recall any specimens not preserved on the matrix characteristic of the Denver formation at Golden.

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[5] The Denver Tertiary formation: Am. Jour. Sci., 3d ser., vol. 37, pp. 272-275, 1889.

[6] Lesquereux, Leo, Harvard Coll. Mus. Comp. Zoology Bull., vol. 16, pp. 43-59, 1888.

The difficulty, not to say danger, of relying implicitly on the matrix to separate collections of questioned stratigraphic position is well illustrated in the attempts made to locate the early collections from Coal Creek, east of Denver. (See p. 90.) This material is preserved on a very soft carbonaceous sandstone and was supposed to have come either from the extreme upper part of the Laramie or from the Arapahoe formation. Recent information derived from a study of the log of a deep well makes it probable that these Coal Creek plants did not come from either the Laramie or the Arapahoe, but from the Denver formation. The study of the matrix of these plants did not and could not settle the horizon with certainty.

Another source of difficulty in dealing with the older collections has arisen in the following manner: It was Lesquereux's custom to publish preliminary accounts, in the annual reports of the Hayden Survey and elsewhere, of the flora of various localities and formations. These included new species more or less adequately described and previously known species, some of them European, but when the formal presentation of the floras was made, as in "The Tertiary flora," or "The Cretaceous and Tertiary floras," certain of these species were merged with other forms and no synonymic record was made of such combinations. It is thus practically impossible now to determine the disposition that was made in such cases, and this explains why forms once reported as present in a flora are no longer accepted, or if admitted are so carefully qualified. A case in point is offered by *Cercis eocenica* Lesquereux. In 1873 this species was named and imperfectly described from "Erie mines, Boulder Valley,"[7] but so far as known it was not afterward alluded to by Lesquereux. It was never figured nor adequately characterized, nor is there known to be a specimen representing it. It was probably united with some other species, but if so there is no record of such transfer.

Another example is furnished by *Quercus lyelli* Heer, a European Tertiary form listed by Lesquereux[8] in his first account of the plants from Marshall, Colo. It was not mentioned again in this connection and has not been since identified from that locality.

Still another series of errors has come from the obvious mislabeling of localities. Under the system at present employed a locality number is placed on each specimen, and it is practically impossible to give a wrong locality, but in the earlier days a single detached label was all that accompanied a whole collection, which might comprise dozens or even hundreds of specimens. When such collections became mixed, as there is undoubted evidence to show that they sometimes did, the only possible way in which the forms can be allocated is by the matrix. If this is sufficiently distinct to be characteristic, the specimens can be separated with a fair degree of certainty, as, for example, when a specimen labeled "Table Mountain, Golden"—which should be in the Denver formation—is found preserved on the whitish arkosic sandstone known to belong to the Laramie of the region, or when a specimen preserved on the andesitic matrix characteristic of the Denver formation is labeled "Black Buttes, Wyo.," where there is a somewhat similar appearing yellowish sandstone, the error can be detected. When the matrix is the same or practically the same, the case is hopeless, and this is undoubtedly the cause for much erroneous distribution of species, both areal and vertical.

I have taken the trouble to explain at length certain of the difficulties encountered in evaluating the original collections. Many toilsome hours have been spent in trying to secure a rational treatment of this material, but even so, it is probably too much to assume that the result is yet or ever will be entirely free from errors of the kind detailed above. This should not be interpreted, however, as meaning that all the older work was uniformly of poor quality, for it was not, but it was pioneer work, with all the handicaps incident to such work, and as such it is to be judged. Whether good or bad, it is the foundation upon which all subsequent effort must be built.

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[7] U. S. Geol. and Geog. Survey Terr. Rept. for 1872, p. 384, 1873.

[8] Lesquereux, Leo, [Notes on fossil plants from Rock Creek, etc.]: Am. Jour. Sci., 2d ser., vol. 45, p. 206, 1868.

SYNONYMS AND CHANGES OF INTERPRETATION.

During the half century that the flora of the Laramie formation has been under consideration by geologists and paleontologists it has naturally happened that there have been many changes in nomenclature and in interpretation. As the literature is more or less widely scattered and difficult of consultation, I have thought it might be of use to have all these changes brought together. The users of this literature will have no difficulty in noting and collating the changes that have taken place by consulting the following alphabetically arranged list:

Acer, fruit and leaves of, Lesquereux, Am. Jour. Sci., 2d ser., vol. 45, p. 208, 1868; Hayden, U. S. Geol. and Geog. Survey Terr. [Third] Ann. Rept., p. 96, 1869 [reprint, p. 196, 1873]. Not subsequently recognized.

Anemia haydenii (Lesquereux) Cockerell=*Anemia elongata* (Newberry) Knowlton, n. comb.

Araucarites reichenbachi Geinitz=*Sequoia reichenbachi* (Geinitz) Heer.

Aspidium goldianum Lesquereux=*Dryopteris lesquereuxii* Knowlton, n. name.

Aspidium fischeri? Lesquereux, 1870=*Dryopteris laramiensis* Knowlton, n. name.

Aspidium (*Lastrea*) *pulchellum?* Heer, Lesquereux, 1870=*Dryopteris laramiensis* Knowlton, n. name.

Caulinites fecundus Lesquereux=*Onoclea fecunda* (Lesquereux) Knowlton.

Clathropodium mirabile (Lesquereux) Ward=*Cycadeoidea mirabilis* (Lesquereux) Ward.

Cornus incompletus Lesquereux, Am. Jour. Sci., 2d ser., vol. 45, p. 208, 1868; Hayden, U. S. Geol. and Geog. Survey Terr. [Third Ann. Rept.], p. 96, 1869 [reprint, p. 196, 1873]. Not described, figured, or subsequently referred to by Lesquereux.

Cornus orbifera Heer, Lesquereux=*Cornus suborbifera* Lesquereux.

Cunninghamites? sp. Knowlton, U. S. Geol. Survey Bull. 163, p. 29, pl. 5, fig. 3, 1900=*Sequoia longifolia* Lesquereux.

Cycadeoidea zamiostrobus Solms=*Cycadeoidea mirabilis* (Lesquereux) Ward.

Echitonium sophiae O. Weber. Lesquereux, Am. Jour. Sci., 2d ser., vol. 45, p. 208, 1868; Hayden, U. S. Geol. and Geog. Survey Terr. [Third] Ann. Rept., p. 96, 1869 [reprint, p. 196, 1873]. Not subsequently recognized from this locality [Marshall, Colo.].

Equisetum laevigatum Lesquereux=*Equisetum perlaevigatum* Cockerell.

Ficus irregularis (Lesquereux) Lesquereux=*Ficus coloradensis* Cockerell.

Ficus lanceolata Heer=*Ficus navicularis* Cockerell.

Ficus lanceolata Heer, U. S. Geol. Survey Bull. 152, p. 102, 1898=*Ficus arenacea* Lesquereux.

Ficus planicostata latifolia Lesquereux=*Ficus cockerelli* Knowlton, n. sp.

Ficus spectabilis Lesquereux=*Ficus denveriana* Cockerell.

Ficus spectabilis Lesquereux, in Peale, U. S. Geol. and Geog. Survey Terr. Rept. for 1873, pp. 203, 393, 1874 =*Ficus denveriana?* Cockerell.

Ficus tiliaefolia Al. Braun. Lesquereux, U. S. Geol. and Geog. Survey Terr. Rept. for 1872, pp. 326, 275, 1873 =*Ficus cockerelli?* Knowlton, n. sp.

Ficus uncata Lesquereux, Knowlton, U. S. Geol. Survey Bull. 152, p. 105, 1898=*Ficus crossii* Ward.

Goniopteris polypodioides Ettingshausen=*Dryopteris* (*Lastrea*) *polypodioides* (Ettingshausen) Knowlton.

Gymnogramma haydenii Lesquereux=*Anemia elongata* (Newberry) Knowlton, n. comb.

Juglans rugosa Lesquereux (in part)=*Juglans praerugosa* Knowlton, n. sp.

Juglans smithsoniana Lesquereux=*Ficus? smithsoniana* (Lesquereux) Lesquereux.

Lastrea (*Goniopteris*) *goldiana* Lesquereux=*Dryopteris lesquereuxii* Knowlton, n. name.

Lastrea (*Goniopteris*) *intermedia* Lesquereux=*Dryopteris laramiensis* Knowlton, n. name.

Lastrea (*Goniopteris*) *polypodioides* (Ettingshausen) Lesquereux, Tertiary flora: U. S. Geol. Survey Terr. Rept., vol. 7, p. 57, pl. 4, figs. 11, 12, 1878=*Dryopteris* (*Lastrea*) *polypodioides* (Ettingshausen) Knowlton.

?Lastrea arguta Lesquereux, Am. Jour. Sci., 2d ser., vol. 45, p. 207, 1868=*Anemia supercretacea* Hollick.

Laurus ocoteoides Lesquereux=*Laurus wardiana* Knowlton.

Myrica? lessigiana Lesquereux=*Artocarpus lessigiana* (Lesquereux) Knowlton.

Myrica? lessigii Lesquereux=*Artocarpus lessigiana* (Lesquereux) Knowlton.

Nelumbium James=*Cycadeoidea mirabilis* (Lesquereux) Ward.

Nelumbium tenuifolium Lesquereux=*Nelumbo tenuifolia* (Lesquereux) Knowlton, n. comb.

Paliurus sp. Lesquereux, in Peale, U. S. Geol. and Geog. Survey Terr. Rept. for 1873, pp. 203, 393, 1874=*Zizyphus coloradensis*? Knowlton, n. sp.

Phragmites oeningensis Al. Braun. Lesquereux=*Phragmites laramianus* Cockerell.

Phyllites sulcatum Lesquereux, Am. Jour. Sci., 2d ser., vol. 45, p. 208, 1868; Hayden, U. S. Geol. and Geog. Survey Terr. [Third] Ann. Rept., p. 96, 1869 [reprint, p. 196, 1873]=nomen nudum. Neither described, figured, nor subsequently referred to by Lesquereux.

Platanus haydenii Newberry. Lesquereux, U. S. Geol. and Geog. Survey Terr. Rept. for 1872, pp. 326, 375, 1873. Not subsequently recognized.

Pteris gardneri Lesquereux=*Gymnogramma gardneri* (Lesquereux) Lesquereux.

Quercus angustiloba Al. Braun. Lesquereux=*Quercus praeangustiloba* Knowlton, n. sp.

Quercus chlorophylla Unger. Lesquereux, Am. Jour. Sci., 2d ser., vol. 45, p. 208, 1868; Hayden, U. S. Geol. and Geog. Survey Terr. [Third] Ann. Rept., p. 96, 1869 [reprint, p. 196, 1873]. Rejected.
Quercus lyelli Heer. Lesquereux, Am. Jour. Sci., 2d ser., vol. 45, p. 208, 1868; Hayden, U. S. Geol. and Geog. Survey Terr. [Third] Ann. Rept., p. 96, 1869 [reprint, p. 196, 1873]. Rejected.
Rhamnus cleburni Lesquereux, in Peale, U. S. Geol. and Geog. Survey Terr. Rept. for 1873, pp. 203, 393, 1874=*Rhamnus* sp.
Rhamnus elegans Newberry = *Rhamnus belmontensis* Knowlton and Cockerell.
Sabal campbelli? Newberry. Lesquereux, U. S. Geol. and Geog. Survey Terr. Rept. for 1872, pp. 326, 375, 1873=*Sabal montana?* Knowlton.
Sabal campbelli? Newberry. Peale, U. S. Geol. and Geog. Survey Terr. Rept. for 1873, pp. 203, 393, 1874= *Sabal montana?* Knowlton.
Sabalites grayanus (Lesquereux) Lesquereux=*Sabal montana* Knowlton.
Salix integra Göppert=*Salix wyomingensis* Knowlton and Cockerell.
Smilax grandifolia? Unger. Lesquereux, in Peale, U. S. Geol. and Geog. Survey Terr. Rept. for 1873, pp. 203, 393, 1874=*Smilax? inquirenda?* Knowlton, n. sp.
Sphenopteris (Asplenium) elongatum Newberry=*Anemia elongata* (Newberry) Knowlton, n. comb.
Ulmus? irregularis Lesquereux=*Ficus coloradensis* Cockerell.
Viburnum platanoides Lesquereux=*Platanus platanoides* (Lesquereux) Knowlton.
Zamiostrobus mirabilis Lesquereux=*Cycadeoidea mirabilis* (Lesquereux) Ward.

LARAMIE PLANTS IN THE DENVER BASIN.

The following is a complete list of the plants found in the Laramie formation in the Denver Basin:

Delesseria fulva Lesquereux.
Onoclea fecunda (Lesquereux) Knowlton.
Dryopteris georgei Knowlton, n. sp.
Dryopteris laramiensis Knowlton n. name.
Dryopteris lesquereuxii Knowlton, n. name.
Dryopteris? carbonensis Knowlton, n. sp.
Phanerophlebites pealei Knowlton, n. gen. and sp.
Asplenium martini Knowlton, n. sp.
Pteris goldmani Knowlton, n. sp.
Pteris? sp.
Anemia elongata (Newberry) Knowlton, n. comb.
Anemia supercretacea Hollick.
Anemia sp.
Lygodium? compactum Lesquereux.
Equisetum perlaevigatum Cockerell.
Dammara sp.
Sequoia acuminata? Lesquereux.
Sequoia reichenbachi (Geinitz) Heer.
Sequoia longifolia Lesquereux.
Cycadeoidea mirabilis (Lesquereux) Ward.
Cyperacites? hillsii Knowlton, n. sp.
Cyperacites? tessellatus Knowlton, n. sp.
Cyperacites? sp.
Phragmites laramianus Cockerell.
Smilax? inquirenda Knowlton, n. sp.
Sabal montana Knowlton, n. sp.
Juglans leydenianus Knowlton, n. sp.
Juglans newberryi Knowlton, n. sp.
Juglans laramiensis Knowlton, n. sp.
Juglans leconteana Lesquereux.
Juglans praerugosa Knowlton, n. sp.
Hicoria angulata Knowlton, n. sp.
Hicoria minutula Knowlton, n. sp.
Myrica torreyi Lesquereux.
Myrica dubia Knowlton, n. sp.
Myrica oblongifolia Knowlton, n. sp.
Salix myricoides Knowlton, n. sp.
Salix wyomingensis Knowlton and Cockerell.
Salix brittoneana Knowlton, n. sp.
Populus? distorta Knowlton, n. sp.
Quercus praeangustiloba Knowlton, n. sp.
Quercus stramineus Lesquereux.
Quercus eximia Knowlton, n. sp.
Quercus viburnifolia? Lesquereux.
Artocarpus lessigiana (Lesquereux) Knowlton.
Artocarpus liriodendroides Knowlton, n. sp.
Ficus? smithsoniana? (Lesquereux) Lesquereux.
Ficus pealei Knowlton, n. sp.
Ficus planicostata Lesquereux.
Ficus cockerelli Knowlton, n. name.
Ficus planicostata magnifolia Knowlton, n. var.
Ficus praeplanicostata Knowlton, n. sp.
Ficus impressa Knowlton, n. sp.
Ficus coloradensis Cockerell.
Ficus dalmatica Ettingshausen.
Ficus neodalmatica Knowlton, n. sp.
Ficus? leyden Knowlton, n. sp.
Ficus posttrinervis Knowlton, n. sp.
Ficus cannoni Knowlton, n. sp.
Ficus navicularis Cockerell.
Ficus multinervis? Heer.
Ficus denveriana? Cockerell.
Ficus crossii Ward.
Ficus cowanensis Knowlton, n. sp.
Ficus berryana Knowlton, n. sp.
Ficus arenacea Lesquereux.
Ficus? apiculatus Knowlton, n. sp.
Aristolochia brittoni Knowlton, n. sp.
Nelumbo tenuifolia (Lesquereux) Knowlton, n. comb.
Magnolia marshalli Knowlton, n. sp.
Magnolia lakesii Knowlton, n. sp.
Anona coloradensis Knowlton, n. sp.
Anona robusta Lesquereux.
Laurus lanceolata Knowlton, n. sp.
Laurus lakesii Knowlton, n. sp.
Laurus wardiana Knowlton.
Malapoenna louisvillensis Knowlton, n. sp.
Cinnamomum affine Lesquereux.
Cinnamomum laramiense Knowlton, n. sp.
Platanus platanoides (Lesquereux) Knowlton.
Leguminosites? coloradensis Knowlton, n. sp.
Leguminosites columbianus Knowlton, n. sp.
Leguminosites? laramiensis Knowlton, n. sp.
Mimosites marshallensis Knowlton, n. sp.
Cassia? laramiensis Knowlton, n. sp.

Cercis eocenica Lesquereux.
Celastrinites alatus Knowlton, n. sp.
Celastrinites eriensis Knowlton, n. sp.
Celastrinites cowanensis Knowlton, n. sp.
Negundo brittoni Knowlton, n. sp.
Pistacia eriensis Knowlton, n. sp.
Pistacia hollicki Knowlton, n. sp.
Ilex laramiensis Knowlton, n. sp.
Ceanothus eriensis Knowlton, n. sp.
Ceanothus ovatifolius Knowlton, n. sp.
Rhamnus goldianus? Lesquereux.
Rhamnus salicifolius Lesquereux.
Rhamnus minutus Knowlton, n. sp.
Rhamnus marshallensis Knowlton, n. sp.
Rhamnus belmontensis Knowlton and Cockerell.
Rhamnus brittoni Knowlton, n. sp.
Rhamnus? pealei Knowlton, n. sp.
Rhamnus sp.
?Paliurus zizyphoides Lesquereux.
Zizyphus coloradensis Knowlton, n. sp.
Zizyphus hendersoni Knowlton, n. sp.
Zizyphus corrugatus Knowlton, n. sp.
Zizyphus minutus Knowlton, n. sp.
Apeibopsis? laramiensis Knowlton, n. sp.
Cornus suborbifera Lesquereux.
Cornus praeimpressa Knowlton, n. sp.
Cornus sp.
Hedera lucens Knowlton, n. sp.
Diospyros berryana Knowlton, n. sp.
Fraxinus? princetoniana Knowlton, n. sp.
Apocynophyllum taenifolium Knowlton, n. sp.
Dombeyopsis obtusa Lesquereux.
Dombeyopsis trivialis Lesquereux.
Dombeyopsis? sinuata Knowlton, n. sp.
Dombeyopsis ovata Knowlton, n. sp.
Carpites lakesii Knowlton, n. sp.
Carpites lesquereuxiana Knowlton, n. sp.
Carpites rhomboidalis Lesquereux.
Phyllites leydenianus Knowlton, n. sp.
Phyllites marshallensis Knowlton, n. sp.
Phyllites trinervis Knowlton, n. sp.
Phyllites dombeyopsoides Knowlton, n. sp.
Phyllites sp.
Phyllites sp.
Phyllites sp.
Palaeoaster? similis Knowlton, n. sp.

BIOLOGIC RELATIONS OF THE FLORA.

The Laramie flora as herein set forth is not an especially rich one as regards specific forms, types of vegetation represented, or individual specimens. Most of the plants have been found in more or less direct connection with the coal. A few of them were found in a fine-grained sandstone or shale, and so far as they are retained in this matrix they are fairly well preserved and admit of satisfactory study. In some places the sandstone matrix, although fine grained, is so hard as to render it difficult to procure perfect specimens, though in perhaps the most fossiliferous localities the matrix is a rather coarse-grained, soft sandstone that crushes or breaks so readily that good material is the exception. As much of the rock disintegrates rapidly on exposure, it is almost impossible to procure identifiable material unless it happens to be collected very soon after it is brought out. All these conditions help to explain why so many of the plants appear fragmentary.

The great group of the algae is represented by a single more or less doubtful specimen that has been referred to the genus *Delesseria.* This is, of course, a very inadequate expression of the algal life that must have existed in the abundant coal swamps and streams of the time. None of the other groups of lower plants below the ferns—that is, fungi, simple algae, mosses, hepatics, etc.—are represented in the collections.

The ferns, although not very abundant as individuals, are diversified in type, being represented by 8 genera and 14 forms. One of the most interesting, but unfortunately also one of the most fragmentary, is represented by the form for which the genus *Phanerophlebites* is created. Its nervation is very similar to that of the living *Phanerophlebia nobilis* (*Aspidium nobile* Chamisso and Schlechtendahl) and *Phanerophlebia juglandifolia* (Willdenow) J. Smith, both from Mexico. What is believed to be the fruiting stage of an *Onoclea* is represented by *Onoclea fecunda,* a form originally described as *Caulinites.* The sterile leaves of this form have not been detected. The largest representation is found in forms referred to *Dryopteris,* of which there are five species. Perhaps the finest of these is the form here named *Dryopteris georgei,* which must have been of rather imposing size and appearance, as the pinnae must have been 15 or 20 centimeters long and 6 to 8 centimeters wide. A small, rather coriaceous form is described as *Dryopteris? carbonensis.* The only form referred to *Asplenium* is fragmentary, but to judge from the portion found it was of striking appearance; it appears to be rather closely allied to a species in the Vermejo formation of the Raton Mesa region. *Pteris* is represented by two forms, neither of which, however, is very well preserved. The Schizaeaceae are represented by a single, rather doubtful species of *Lygodium* and three forms of *Anemia.* A single species of *Equisetum* represents the Equisetaceae.

The conifers appear to have been an unimportant element, as regards both forms and individuals, in this flora, being represented by only two genera and four forms. Of these *Dammara* is represented by a single fragmentary scale and, of course, is of little importance. The species of *Sequoia* are represented by several leafy branchlets.

The only example belonging to the Cycadaceae is a beautifully preserved small trunk now referred to *Cycadeoidea*, but unfortunately its exact horizon is open to question.

The monocotyledons were apparently not an abundant element during the Cretaceous period, and the Laramie flora is no exception, though the number and variety present are rather greater than might have been expected. There are, for example, three forms of sedgelike plants described under the name *Cyperacites*, and a single grass with strong, reedlike stems, designated *Phragmites*, that must have been a striking denizen of the swamps. The flora contains also a fairly well-marked leaf of a *Smilax*, and two species of palms, one of which at least had leaves of large size and imposing appearance.

The dicotyledons were, of course, the most abundant and diversified elements of this flora. Beginning with the lower or apetalous groups, we have five species of *Juglans* known from the leaves, and two of *Hicoria* known from the fruits. The waxberries were represented by three or four forms of *Myrica*, and the willows by the species of *Salix*, some of which were individually abundant. One species of *Populus* is described, though it is neither abundant nor very well marked. The oaks are represented by four forms of *Quercus*, one of which (*Q. praeangustiloba*) was a deeply lobed leaf of modern appearance.

The large, mainly tropical family Moraceae was apparently an abundant and diversified element, embracing two species of *Artocarpus* or breadfruit that possessed very strongly marked leaves and 21 species of *Ficus*. The figs were not only more abundant in species but also in individuals, as there is hardly a collection that does not contain from one to several species. A number of the species have leaves of large size.

Aristolochia was represented by a single species with leaves of much the same shape as two well-known European forms. In both form and nervation it approaches an American species (*A. sipho*). To the Nymphaeaceae is referred a fine species of *Nelumbo* with large peltate leaves.

The Magnoliaceae, although represented by two species of *Magnolia*, were neither abundant nor of especially striking aspect, as the small leaves indicate.

The Lauraceae embrace three genera and five species—*Laurus* with two, *Malapoenna* with one, and *Cinnamomum* with two. *Cinnamomum affine* was abundant and widely distributed.

The Platanaceae were very poorly represented, there being only one small-leaved form and a doubtful fragment not specifically named. The named species (*Platanus platanoides*) was first referred to *Viburnum*, and its reference to *Platanus* is not positively authenticated.

The Leguminosae are supposed to be represented by three forms of *Leguminosites*, one of *Mimosites*, and a very doubtful *Cercis*. The two forms of *Celastrinites* and one of *Negundo* show little of special biologic interest. There are three forms of *Cornus*, two each of *Anona* and *Pistacia*, four of *Dombeyopsis*, and one each of *Fraxinus*, *Apocynophyllum*, *Hedera*, and *Ilex*. Of the more or less indefinite *Carpites* there are four, and of *Phyllites* about seven forms.

ECOLOGIC RELATIONS OF THE FLORA.

After having briefly reviewed the Laramie flora, we are in position to draw at least tentative conclusions regarding the ecologic conditions which appear to have existed during Laramie time. As I have had occasion to remark in another similar connection:

> In estimating the value of individual organisms in an inquiry of this kind, dependence must of course be placed on our knowledge of present-day requirements, and in this there is always the possibility of error from two sources, namely, (1) the organism may not have been correctly placed biologically, and (2) the requirements in past geologic time may not have been the same as those which now dominate the life activities of its supposed analogue. However, when all of the elements of a flora appear with apparent unanimity to point in the same direction, the liability to serious error is minimized if not eliminated.

The presence of very considerable veins of coal, which occur mainly in the lower portion of the formation, undoubtedly calls for widespread and long-continued swamp or marsh conditions. David White,[9] in speaking of the physiographic conditions attending the formation of coal, said:

> The enormous horizontal extent of many of the coal groups as indicated by the remnants now found in basins detached as the result of folding and erosion, the demonstrated continuity of some of the individual coal beds over areas of amazing size, the high degree of parallelism of the beds, and the recognition that the coal beds were laid down beneath a water cover join in predicating the existence, at the time the coal was being formed, of vast swamps and broad but shallow lagoonal areas subject to subsidence at a generally slow rate.

The above is known as the autocthonous (formed in place) hypothesis of the origin of coal. It is but fair to state, however, that the allocthonous (transported) hypothesis, which argues that much of the coal may have been formed by floating and sedimentation at the bottom of open lakes or lagoons, has still an occasional advocate. In a recent article on "The mode of origin of coal" E. C. Jeffrey[10] set forth the results of the microscopic examination of great numbers of coals from all parts of the world and from horizons ranging from Devonian to Tertiary. He held that he is able to distinguish the relatively few types that appear to have been formed under peat-swamp conditions and asserted that the vast majority give evidence of deposition in open water. "Coal is not a compost heap but a sedimentary deposit," he concluded. Be this as it may, it is not within the scope of the present paper further to discuss the origin of coal.

Concerning the interpretation of the climates of the coal-forming periods, White said:

> It will be seen that during the times of deposition of most of the principal coal groups the climate has been characterized by (1) general mildness of temperature, approaching in most cases tropical or subtropical conditions; (2) conspicuous equability or approximation to uniformity of climatic conditions, which, with few exceptions, appear to have lacked cold winters or severe frosts; (3) a generally high humidity, the rainfall being from moderately heavy to very heavy and fairly well distributed during the year, though in many cases there is evidence of the occurrence of dry periods, which, however, seem ordinarily to have been comparatively short and not severe; (4) an amazingly wide geographical distribution of these genial and equable climates.

To repeat, then—the abundant presence of coal in the Laramie of the Denver Basin offers in itself sufficient proof of the existence of long-continued, relatively uniform swamp or marsh conditions. According to currently accepted theories a larger percentage of all coals were formed by accumulations of vegetable matter under conditions similar to those existing in a modern peat swamp. The types of vegetation that contributed to the formation of the coals depend of course upon the geologic period during which they were laid down; but whatever the age, the process is believed to have been essentially identical throughout.

We may now examine the plants found in the flora under discussion to ascertain if possible which of its members appear to demand a habitat that would make it a potential contribution to or at home in such a peat-producing environment. The sedgelike plants described as *Cyperacites* might very well have found a home in such a swamp, and the tall, canelike grass *Phragmites* is notably such a swamp-loving plant. *Smilax*—or at least the form to which the Laramie species seems to be related—is essentially a denizen of swamps and low places, where it often forms dense tangles. Equally at home in or about a swamp, or along adjacent watercourses, would be found the waxberries (*Myrica*), willows, and poplars, while the shallow, quiet waters furnished a congenial surrounding for the floating leaves of *Nelumbo*. Among the ferns there are several, such as *Onoclea*, *Lygodium*, and *Anemia*, that might well have found a home in or near swampy or low ground, while the others, including *Asplenium*, *Dryopteris*, etc., demand shade and moisture such as is afforded in or adjacent to low ground.

If the data have been correctly interpreted, the Moraceae formed the most conspicuous group in this flora, comprising two genera and nearly 25 species. Of these *Artocarpus* is represented by two very well-marked forms. The members of this genus at the present time demand a warm, moist habitat such as might be afforded by the swamp we are predicating. In the same way the several species of *Ficus* call for like conditions. This great swamp may well have harbored also the two *Magnolias*, the *Fraxinus*, and possibly the *Zizyphus*, and about its border the two palms may have had their home.

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[9] White, David, and Thiessen, Reinhardt, The origin of coal: Bur. Mines Bull. 38, p. 53, 1913.

[10] Jour. Geology, vol. 23, pp. 218–230, 1915.

The conifers do not offer very definite evidence and, moreover, are so rare in individuals that they could hardly have been a conspicuous element. It is probable that they grew on adjacent higher ground and found their way into the deposits through the agency of streams. Growing with them on higher ground may well have been the *Cornus*, *Quercus*, *Juglans*, *Hicoria*, *Rhamnus*, *Hedera*, *Ilex*, etc., which complete the picture.

We may now proceed to draw some perhaps tentative conclusions as to the climatic conditions under which the Laramie flora may be presumed to have existed. From the abundant presence of coal and the apparent requirements of the majority of the plants enumerated, it is beyond question that there must have been an abundance of moisture. It also appears naturally to follow from the presumed requirements of the flora that the climate was warm, at least warm temperate.

GEOLOGIC RELATIONS OF THE FLORA.

Naturally one of the most interesting and important phases of this study of the Laramie flora is the bearing it may have on the interpretation of the age and stratigraphic relations of the beds in which it occurs. As has been so abundantly shown in the section on the historical treatment of the term Laramie, this term has been so bandied about that at one time its significance as a stratigraphic designation had been practically lost or at least greatly obscured. Much of the earlier paleobotanic work on the flora was rendered unavailable for the reason that practically every student had a different concept of the Laramie, and this could only lead to irreconcilable confusion. The present study was undertaken in the hope that by taking a comparatively small area and thoroughly working up its flora, data might be obtained that would serve as a basis for comparison elsewhere. It remains to be seen how far this desire has been realized.

The flora of the Laramie in the Denver Basin comprises 129 forms, of which 74 are here described as new to science, 8 forms have been regarded as too fragmentary or obscure to warrant being named specifically, and 47 forms have been previously named and described. It is to be noted, however, that although the proportion of new forms may seem to be large, many of them have been known to the writer for years; in fact, the descriptions of perhaps more than half of them have been in manuscript since about 1895 and have been utilized in discussions of this and related floras.

RELATIONS TO THE MONTANA FORMATIONS.

The Laramie flora, as might perhaps be expected, is on the whole most closely related, either by identical or obviously related species, to the Montana flora, yet with adequate collections there should be no difficulty in separating them. As the unconformity which separates the Laramie from the Arapahoe and Denver formations is believed to be the same as that which separates the Vermejo from the overlying Raton formation in the Raton Mesa region, it might be presumed that there should be a close correspondence between the Laramie and the Vermejo, but a critical study of the floras does not bear out this presumption. At first it was thought that only a single species (*Rhamnus salicifolius*) was common to the two formations, but later study discloses the fact that there are five or six species that occur in both. Inasmuch as there are 106 species in the Vermejo and 129 in the Laramie, however, the relationship obviously is not very strong. The species in common are as follows:

Sequoia reichenbachi (Geinitz) Heer.
Sabal montana Knowlton.
Myrica torreyi Lesquereux.
Ficus dalmatica Ettingshausen.
Ficus trinervis Knowlton.
Rhamnus salicifolius Lesquereux.

Of these species, *Sequoia reichenbachi* has an almost worldwide distribution and ranges in age from Jurassic to Upper Cretaceous, and it is therefore of no importance as a close horizon marker. The known presence of this species in the Laramie rests on a few more or less doubtful fragments, though if correctly identified its rarity has, of course, no bearing in the present consideration. *Sabal montana* is a very large leaved species, perhaps the largest-leaved Rocky Mountain form, and as a consequence it is rather rarely found in perfect condition. There is little doubt, however, that it occurs in both Vermejo and Laramie. *Myrica torreyi*, though occurring mainly in the Montana, is a widely ranging form and has even been found in beds above the unconformity. *Rhamnus saliciformis* was described originally from specimens obtained in the Laramie and has subsequently been found in the Montana at a number of horizons. The two species of *Ficus* are well-marked forms and probably have been correctly identified in both areas.

In addition to the flora of the Vermejo, which is of course of Montana age, it may be of interest to compare the Laramie flora with the Montana flora as a whole. The following species are common to the two:

Anemia elongata (Newberry).
?Anemia supercretacea Hollick.
Sequoia reichenbachi (Geinitz) Heer.
Sequoia longifolia (Lesquereux) Knowlton.
Sabal montana Knowlton.
Myrica torreyi Lesquereux.
Ficus dalmatica Ettingshausen.
Ficus praetrinervis Knowlton.
Ficus planicostata Lesquereux.
Rhamnus salicifolius Lesquereux.

In addition to the species that are regarded as actually identical in the Laramie and Montana floras, there are two that are obviously related to Montana species, as follows:

Palaeoaster? similis, aff. P. inquirenda.
Artocarpus liriodendroides, aff. A. dissecta.

RELATIONS TO THE "LOWER LARAMIE" OF CARBON COUNTY, WYO.

One of the most interesting results brought out by this study is the close relation that is shown to exist between the flora of the Laramie in the Denver Basin and the flora of the so-called "Lower Laramie" (now the Medicine Bow formation) of Carbon County, Wyo., and adjacent areas. The flora of the "Lower Laramie" at present known is confined in the main to the lower 300 or 400 feet of beds, and though it has not yet been fully exploited, the following forms at least are known to occur:

Apeibopsis discolor Lesquereux.
Aristolochia sp.
*Artocarpus lessigii (Lesquereux) Knowlton.
Carpites sp.
*Cassia marshallensis Knowlton.
Ceanothus? sp.
*Cinnamomum affine Lesquereux.
*Cyperacites sp.?
Daphnogene elegans Watelet.
Diospyros? ficoidea Lesquereux.
*Dombeyopsis obtusa Lesquereux.
*Dombeyopsis trivialis Lesquereux.
Dryophyllum cf. D. aquamarum Ward.
Dryophyllum bruneri Ward.
*Dryopteris carbonensis Knowlton.
Equisetum, tubers of.
*Ficus arenacea Lesquereux.
*Ficus impressa.
*Ficus cockerelli Knowlton.
*Ficus navicularis Cockerell.
*Ficus planicostata? Lesquereux.
*Ficus praetrinervis Knowlton.
Ficus sp., new.
Ficus? sp.
*Sequoia longifolia Lesquereux.
Geonomites cf. G. ungeri Lesquereux.
Ilex? sp.
*Juglans praerugosa.
*Laurus wardiana Knowlton.
Mimosites? sp.
Mimosa sp.?
*Myrica torreyi Lesquereux.
Paliurus zizyphoides?
Palmoxylon sp., new?
*Pecopteris sepulta Newberry cf. Hollick.
*Phyllites sp.
Pistia corrugata? Lesquereux.
Platanus marginata (Lesquereux) Heer.
*Platanus platanoides (Lesquereux) Knowlton.
*Rhamnus elegans Newberry.
*Rhamnus saliciformis Lesquereux.
*Sabal montana Knowlton.
*Salix elongata? Al. Braun.
Salix sp.
*Sequoia reichenbachi (Geinitz) Heer.
Sequoia sp.
Woodwardia, new, nearest to W. crenata Knowlton.
*Zizyphus minimus Knowlton.

An analysis of the above list shows that it contains 48 forms, of which 26, marked with an asterisk in the list, are named species having a distribution outside this area. Of these 26 species no less than 25 are found also in the Laramie of the Denver Basin, and it therefore seems legitimate to conclude that the age of the beds is the same in the two areas. As set forth at length on page 60, the section of "Lower Laramie" rocks has a thickness of about 6,000 feet. According to Veatch, this thick section is separated from the overlying beds (now called the Ferris formation) by an unconformity which he regarded as profound, because it was believed to have involved the removal of more than 20,000 feet of sediments. This unconformity was presumed to be the same as that which separates the Laramie from the overlying Arapahoe and Denver formations in the Denver Basin, but as a result of later work Bowen would place this unconformity at the top of the Ferris formation and not at its base, though not denying the possibility of an unconformity at the base of the Ferris. That this may be the correct interpretation finds physiographic support in a paper read by W. T. Lee[11] before the Geological Society of Washington, entitled "Relation of the Cretaceous formations to the Rocky Mountains." In this paper data were presented to show that the entire marine Upper Cretaceous section was laid down uninterruptedly over the area now occupied by the Rocky Mountains. Lee held

> that the Cretaceous sediments of the Rocky Mountain region came mainly from the continental land mass that lay west of the interior sea during Cretaceous time. * * * Comparisons of published sections viewed in the light of personal observation in the field indicate that the Cretaceous formations on opposite sides of the mountains and in the intermontane basins are comparable in thickness, character, and stratigraphic succession. * * * It seems probable that the interior Cretaceous basin, which includes the present Rocky Mountain areas, was a great geosyncline in which, until near the close of the Cretaceous, the main movement was downward, with minor warpings. It also seems probable that there was no effective barrier in the relatively small area now occupied by the mountains to prevent the uniform spread of sediments derived from the continental mass west of the Cretaceous sea.

If, as Lee contended, the entire marine Upper Cretaceous section was laid down over the Rocky Mountain area, there is every reason to suppose that the Laramie was also, for it is everywhere conformable with the marine beds on which it rests; indeed, the definition of the Laramie—as the uppermost member of the conformable Cretaceous section above the Fox Hills—demands that it be considered with the marine portion of the section. With the uplifting of the Rocky Mountains came erosion and unconformity. In the Denver Basin the Laramie has a maximum thickness of approximately 1,200 feet, but 90 miles to the south, in the Colorado Springs area, it is reduced to less than 400 feet, and in the Raton Mesa region the Laramie has entirely disappeared and the Eocene (Raton formation) there rests on the Montana (Vermejo formation). In North Park, Colo., the Laramie is not known to be present, but in Carbon County, Wyo., the "Lower Laramie" occupies the same stratigraphic position as the Laramie of the Denver Basin and has a thickness of several thousand feet. The strong similarity of the floras of the Medicine Bow and the Laramie of the Denver Basin is interpreted as evidence of identity in age.

For an account of the latest interpretation of the stratigraphic relation in Carbon County as worked out by Bowen, the reader is referred to page 60.

It remains to be pointed out that the fossil plants support the contention of Veatch, perhaps as modified by Bowen, namely, that there are some 5,000 or 6,000 feet of beds in the "Lower Laramie," and that this portion, at least, is of the same age as the true Laramie of the Denver Basin. In my opinion the "Lower Laramie" is not Lance. On the other hand I believe that the Lance is to be correlated with a part of the "Upper Laramie" of this region, a view supported by the plants and in the main by the vertebrates also.

RELATIONS TO THE DENVER FORMATION.

The following species are common to the Laramie and Denver formations:

Sequoia acuminata Lesquereux.
Quercus viburnifolia Lesquereux.
Ficus coloradensis Cockerell.
Ficus denveriana? Cockerell.
Nelumbo tenuifolia (Lesquereux) Knowlton.
Dombeyopsis obtusa Lesquereux.
Laurus wardiana? Knowlton.
Paliurus zizyphoides? Lesquereux.
Rhamnus salicifolius Lesquereux.

The flora of the Denver formation numbers about 98 named and described species, but in addition to these there are a number of others in manuscript or otherwise recognized, which will bring the total number up to about 225. Nine species in common is really a very small number.

The status of the several species in this list may be briefly considered. *Sequoia acuminata* was described originally from specimens obtained at Black Buttes, Wyo. Its presence in the Laramie of the Denver Basin rests on a single, rather doubtful fragment found at Cowan station, near Denver, and its presence in the Dawson arkose rests on a specimen found near Templeton Gap, 4 miles northeast of Colorado Springs. *Ficus coloradensis* is one of the most satisfactorily identified of the species occurring in both Laramie and Denver in the Denver Basin. The types are preserved in the characteristic andesitic material from Golden, Colo., and it has been found in subsequent collections from the same horizons. It occurs in the Laramie at Marshall and 1½ miles south of Golden. A discussion of its reported presence at Point of Rocks and Black Buttes, Wyo., will be found in the systematic treatment of the species (p. 134). *Ficus denveriana* (*F. spectabilis* Lesquereux) is essentially a Denver species, and its occurrence in the Laramie depends on a doubtfully determined leaf from Popes Bluff, near Colorado Springs. *Dombeyopsis obtusa* was first obtained from the Laramie at Popes Bluff and has since been noted in the Laramie at Coal Creek, Marshall, Hoyt's mine, south of Golden, and Crow Creek, northeast of Greeley; in the Dawson arkose at Pulpit Rock; and in the Denver at the Douglas coal mine, Sedalia. Though it is more abundant in the Laramie it is undoubtedly present in the post-Laramie beds as above indicated. *Laurus wardiana* is a rare species, known positively only from a single leaf from Golden and questionably in the supposed Dawson near Mosby, Colo. *Paliurus zizyphoides* was established on material from Black Buttes, Wyo., and was reported by Lesquereux to have been found also in the Laramie at Erie and the supposed Laramie at Sand Creek, Colo., but no specimens from these localities are known to exist. *Rhamnus salicifolius* was described from material obtained in the Laramie at Marshall and has since been found at Cowan station, near Denver. Its presence in the Dawson arkose depends on specimens from Templeton Gap, near Colorado Springs. It also occurs in the Vermejo formation, the Montana group of Wyoming, and elsewhere.

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[11] Washington Acad. Sci. Jour., vol. 5, pp. 29-33, 1915; U. S. Geol. Survey Prof. Paper 95, pp. 27-58, 1915.

RELATIONS TO THE ARAPAHOE FORMATION.

Before it will be possible to consider any relation between the flora of the Laramie and that of the Arapahoe, it will be necessary to review with some care the present status of knowledge concerning the Arapahoe flora. According to Eldridge, on whom largely devolved the task of studying the Arapahoe formation for the Denver Basin monograph, the formation was found to contain poorly preserved fossil leaves at a number of localities within the Denver region, but no determinable species were collected. Only two localities were known from which determinable plants supposed to be of Arapahoe age have been reported—Sand Creek, east of Denver, and the vicinity of the Douglas coal mine, Sedalia, about 20 miles south of Denver.

Some 9 or 10 species of plants are recorded as having come from the Sand Creek locality, all of which were obtained by the earlier workers in this field—that is, probably about 1873. Considerable uncertainty has existed as to the exact locality whence these plants came, but apparently important light is thrown on this point by a chance statement made by A. R. Marvine[12] in his paper on "The geology of Middle Park," which on account of its importance is quoted entire below.

> East of Denver, in T. 4 S., and probably between Rs. 65 and 66 W., a shaft has been sunk for some depth in a high bank on the south side of Sand Creek but is now abandoned. The coal also outcrops on the bank and there appears as of very poor quality. Fossil leaves are abundant.
>
> It was near here that the first discoveries of coal were made in Colorado, and the stream at this point is often known as Coal Creek, though called Sand Creek further down. The latter name should be retained, to prevent confusion between this and the better-known Coal Creek on the west side of the Platte.
>
> About 4 miles to the north, near Box Elder, on the Kansas Pacific Railroad, in R. 65 W., T. 3 S., sec. 28 (?), and probably at the same horizon as the last, are two shafts which reach coal and on which work has been done now and then for some years. It is probably in one of these three shafts that the following section was made by Mr. E. B. Mally (quoted by Lesquereux in Hayden's report for 1872, p. 327), and which seems to give an idea of the strata near here. * * *
>
> The work was abandoned on account of the poor quality of the coal.

That the above-indicated plant-bearing horizon is probably the important one in the present consideration was still further indicated by Marvine, who, after mentioning a number of coal openings in another direction from Denver, said: "The only others I have heard of lie from 15 to 17 miles east of Denver City and near the Box Elder station on the Kansas Pacific Railroad." The assumption seems to be justified, therefore, that the plants labeled "Sand Creek" probably came from this area.

In Lesquereux's "Tertiary flora" the following data are recorded concerning six of the species reported to have come from Sand Creek:

Lastrea (G.) polypodiodes. Sand Creek (W. H. Holmes).
Gymnogramma gardneri. Roof of a coal mine, Sand Creek (A. Gardner).
Equisetum laevigatum. Sand Creek, 8 feet above coal (W. H. Holmes).
Eriocaulon? porosum. Sand Creek (W. H. Holmes) with leaves of Nelumbium.

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[12] U. S. Geol. and Geog. Survey Terr. Rept. for 1873, pp. 120, 121, 1874.

Nelumbium tenuifolium. Sand Creek, Colorado (Prof. A. Gardner).

Quercus viburnifolia. Sand Creek (A. R. Marvine).

These species are similarly recorded in the catalogue of fossil plants in the United States National Museum, in Lesquereux's own handwriting, so it may be presumed that the statements are correct, at least so far as his information went. The species obtained by Marvine was doubtless collected on the occasion of his visit there in 1873, but no data are available as to the date on which the two species accredited to Prof. Gardner were collected. W. H. Holmes assisted Marvine in his geologic work in 1873, and the plants recorded as having been collected by him were probably obtained at that time, but on consultation with Prof. Holmes I find that he has now no recollection of having collected the plants, or, indeed, of having visited any coal mines east of Denver. This injects another element of uncertainty into the already sufficiently complicated matter, but we shall probably never come any nearer to a complete explanation. To sum up, it appears in its final analysis that we do not know the precise locality for a single one of these Sand Creek plants, though in all reasonable probability they apparently came from the vicinity of the coal openings on Coal or Sand Creek about 15 miles east of Denver; but as the locality is in doubt, it naturally follows that the horizon is also uncertain. It was apparently assumed by Cross that they came from the Arapahoe, for he stated that along Sand Creek this formation rests on the Laramie, but according to the map showing the areal geology in the Denver Basin monograph, the Laramie occurs on the north bank of the creek, and the Denver on the south bank, no Arapahoe being indicated. Cross,[13] in discussing the Sand Creek locality, said: "The specimens preserved in the National Museum do not satisfactorily indicate the horizon from which they came. It seems probable that a part of them came from the Arapahoe beds and a part from the Laramie."

Up to this point, from the data available, it appeared to me that if any of the Sand Creek plants came from the Laramie they probably all did, and on this basis it was my original intention to include them provisionally in the present work. However, important observations made by W. T. Lee during the field season of 1915 put an entirely different light on the matter and have led me to exclude all the Sand Creek species from both Arapahoe and Laramie, and to refer them with little or no question to the Denver. The evidence is as follows: Lee examined the log of a deep well that has been drilled about 2½ miles northeast of Coal Creek (or Sand Creek). This well starts at the surface in sandy coal-bearing beds that are lithologically and stratigraphically identical with the beds in question along Sand Creek, and are also the same as the coal-bearing beds at Scranton, which from the presence of coal are supposed to be in the upper part of the Laramie. Lee's description of the well is as follows:

Section of oil well east of Denver, Colo., in sec. 24, T. 3 S., R. 67 W.

		Feet.
Denver:		
Clay, sand, and gravel		200
Coal	Scranton coal.	2
Clay, sand, and arkose.		248
Coal		4
Sand, gravel, and clay		346
Arapahoe:		
Conglomerate		50
Laramie:		
Soft blue shale		175
Sandstone and shale alternating		275
Shale, light colored		140
Shale, dark colored		35
Brown shale		65
Coal		10
Fox Hills:		
Massive sandstone containing artesian water		130
Shale		10
Sandstone		20
Pierre:		
Shale and limestone (shells)		1,500+

The facts brought out by this well record are of far-reaching significance. It shows that the Scranton coal, heretofore thought to be in the upper part of the Laramie, is about 350 feet above what is believed to be the Arapahoe conglomerate. This conglomerate is about 50 feet thick. It also appears that the Scranton coal is more than 400 feet above beds that can with reasonableness be referred to the Laramie, and more than 1,000 feet above the main Laramie coal. The thickness of beds between the Scranton coal and the main Laramie coal is not of particular significance in view of the fact that the maximum thickness previously assigned to the Laramie in this area was about 1,600 feet. The crucial point is the disclosure of the Arapahoe conglomerate between the two coal horizons, which naturally tends to decrease the observed thickness of the Laramie strata.

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[13] Cross, Whitman, U. S. Geol. Survey Mon. 27, p. 225, 1896.

The other supposed locality for Arapahoe plants—namely, that near the Douglas coal mine, west of Sedalia—may now be considered. As this is at or near the type locality for the Arapahoe there should apparently be no question as to its relation, but it appears from the work of G. B. Richardson, who critically studied this area in 1910–11, that the Arapahoe occupies the stratigraphic position of the Dawson arkose and in fact interdigitates with the lower part of it. Concerning this point Richardson [14] wrote as follows: "It was found that the lower part of the Dawson arkose seems to pass along the strike into the Arapahoe and Denver formations; that the Dawson and Arapahoe can not be separated lithologically, even at the type locality of Arapahoe, on the bluffs of Willow Creek." This conclusion does not, of course, affect the stratigraphic relations of the plant-bearing beds, and it is unimportant whether the beds are to be called Arapahoe or Dawson, as they are separated from the underlying Laramie by an unconformity marking a considerable time interval.

Below is a tentative list of the plants from the Douglas mine locality as worked up about 12 years ago. Additional material not yet studied may necessitate slight changes, though it is not presumed that these will greatly affect the result.

Acer trilobatum productum.
Asplenium erosum.
Berchemia multinervis.
Cissus laevigata.
Cissus lobato-crenata.
Dicksonia, new.
Diospyros brachysepala?
Dombeyopsis obtusa.
Dombeyopsis, new.
Dryopteris lakesii.
Dryopteris lesquereuxii?
Ficus planicostata.
Ficus, new.
Hicoria? sp.
Laurus primigenia.
Nelumbo lakesii.
Nelumbo, new.
Phyllites, new.
Quercus, new.
Viburnum, new.
Woodwardia latiloba.

It will be seen at once that this is essentially a Denver flora, with only two species that occur in the Laramie—*Dombeyopsis obtusa* and *Ficus planicostata*. Both of these species have already been several times mentioned as passing from Laramie into post-Laramie beds.

RELATIONS TO THE LANCE FORMATION.

It is difficult at present to make an accurate and wholly satisfactory comparison between the flora of the Laramie in the Denver Basin and the flora of the Lance formation. This difficulty arises from the fact that the Lance flora has not yet been thoroughly worked up and described. It is known that the Lance flora comprises approximately 125 forms. It is possible that when this flora has been fully described, the number of species found to be in common with the Laramie may be slightly increased over the number given below, but it is improbable that they will be increased to as many as twice that number. Another difficulty in the way of making an accurate comparison between these two floras is the uncertainty that still attaches to certain of the localities that have afforded some of the supposed Lance plants. It is perhaps unnecessary to state that there has been—and indeed still is—more or less uncertainty in fixing the limits of the Lance formation, though the difficulty is much greater in fixing the upper limit than it is in fixing the lower limit. Be this as it may, the species mentioned below are the only ones that are at present recognized as passing from the Laramie into the Lance.

Equisetum perlaevigatum.
Myrica torreyi.
Ficus planicostata.
Cinnamomum affine??
Rhamnus salicifolius.
Platanus platanoides.
Quercus viburnifolia?

A discussion of these species may be of interest. Thus, *Equisetum laevigatum* (now *perlaevigatum*) was reported by Hollick from the so-called "Hell Creek beds" (Lance) in the vicinity of Hell Creek, Mont. In the descriptive part of this paper (p. 113) it is stated that this species was founded on two specimens, one of which (from Sand Creek, Colo., in beds now believed to be of Denver age) is probably only a piece of bark, and the other (from the true Laramie at Golden, Colo.) is based on a portion of an underground stem of an *Equisetum* with characters so poorly defined that the advisability of retaining it is open to question. It is not to be doubted that there are *Equisetum* stems in the "Hell Creek beds," but the propriety of identifying them with *Equisetum perlaevigatum* may well be questioned. *Rhamnus salicifolius* is another of the forms identified by Hollick in the "Hell Creek beds." This, together with *Myrica torreyi*, is well known as a species enjoying a wide vertical range. *Ficus planicostata* is also a species of considerable vertical range. It is extremely rare in the Lance formation, and its identification is not beyond question. The identification of *Cinnamomum affine* rests on its doubtful presence in the Kingsbury conglomerate, east of the Big Horn Mountains, Wyo., and *Quercus viburnifolia* was identified with question at Forsyth, Mont.

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[14] Richardson, G. B., The Monument Creek group: Geol. Soc. America Bull., vol. 23, p. 274, 1912.

In a paper published in 1909[15] I listed 11 species that were at that time believed to be common to the Laramie and Lance formations. The species additional to those in the above list are *Ficus trinervis*, *Flabellaria eocenica*, *Sabalites grayanus*, and *Juglans rugosa*. According to present understanding neither *Ficus trinervis* nor *Juglans rugosa* is known in the Laramie of the Denver Basin. The two palms may be the same as the Montana and Laramie form known as *Sabal montana*, but there is usually difficulty in certainly identifying remains of palms.

From this brief account it appears that there are not now known to be more than four or five species of plants that are common to the Laramie and Lance, and when it is recalled that there is about the same number of species in the two floras, it is seen that the relationship between these floras is not a strong one.

RELATIONS TO THE UPPERMOST CRETACEOUS OF THE ATLANTIC COASTAL PLAIN.

In the major portion of the Atlantic Coastal Plain the uppermost Cretaceous is believed to be either lower in position than the Laramie, or where the section is more nearly complete—as in the northern portion—it is a marine deposit and not plant-bearing.

RELATIONS TO THE PATOOT SERIES OF GREENLAND.

The Cretaceous system is very considerably developed in Greenland, reaching a thickness of approximately 4,000 feet. The area of exposure includes Disco Island and the Nugsuak Peninsula and is a belt about 75 miles wide along the deeply indented coast line from latitude 69° 15′ to 72° 15′ N. The beds at many places are very fossiliferous and have yielded altogether more than 350 species of plants, which were, in the main, elaborated by Oswald Heer in his well-known "Flora fossilis arctica," comprising seven quarto volumes, published in 1868 to 1883. On the basis of the plants, Heer divided the Cretaceous into three series. A lower division, called the Kome series, with a flora of 88 species, was correlated with the Urgonian of Europe; a middle division, the Atane series, with 177 species of plants, was correlated with the Cenomanian; and an upper division, the Patoot series, with a flora of 123 species, was correlated with the European Senonian and the Fox Hills of the United States. Above this in other parts of the Arctic region is a considerable thickness of Tertiary beds, also with an abundant flora, which constitute the so-called Arctic Miocene, now very generally referred to the Eocene.

The Atane and Patoot series have a combined thickness of at least 1,300 feet, and probably considerably more. There is no sharp line of demarcation between them, the boundary having been drawn by Heer purely on paleontologic grounds.

Although Heer definitely correlated the Patoot series with the Senonian, White and Schuchert,[16] who visited the region in 1897, expressed the view that there was a transition without sedimentary break into the overlying Tertiary. These writers also stated that the Patoot series contains "many plants common to the upper part of the Amboy clays, with others allied more closely to the higher Cretaceous flora, such as that of the Laramie."

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[15] Knowlton, F. H., Stratigraphic relations and paleontology of the "Hell Creek beds," "*Ceratops* beds," and equivalents, and their reference to the Fort Union formation: Washington Acad. Sci. Proc., vol. 11, p. 222, 1909.

[16] White, David, and Schuchert, Charles, Cretaceous series of the west coast of Greenland: Geol. Soc. America Bull., vol. 9, p. 367, 1898.

Subsequent study of the Laramie flora. however, does not bear out this suggestion, for so far as now known the two floras contain no species in common. This is also the view reached by Berry,[17] who pointed out that of the 123 Patoot species 20 occur in the Dakota sandstone, 22 in the Raritan, 19 in the Magothy, 8 in the Tuscaloosa, and 4 in the Black Creek formation. He says: "The large number of Atane species present (34), as well as the numerous Dakota, Raritan, and Magothy species, precludes considering the flora as young as, for example, the Laramie."

It may be accepted, then, that the Laramie flora is younger than that of the Patoot series and there is little or no relation between them.

RELATIONS TO THE UPPER CRETACEOUS OF EUROPE.

As a preliminary to the consideration of the possible relations between the flora of the Laramie and such floras as are available in the European Upper Cretaceous, it may be of interest to give a brief tabular view of the Upper Cretaceous section that is now quite generally accepted. It is taken in the main from the fifth edition of De Lapparent's Geology:

Danian.

$$\text{Aturian}\left\{\begin{matrix}\text{Maestrichtian}\\ \text{Campanian}\end{matrix}\right\}\text{Upper Senonian.}$$

$$\text{Emscherian}\left\{\begin{matrix}\text{Santonian}\\ \text{Coniacian}\end{matrix}\right\}\text{Lower Senonian.}$$

$$\text{Turonian}\left\{\begin{matrix}\text{Angoumian.}\\ \text{Ligerian.}\end{matrix}\right.$$

Cenomanian.

The Campanian, the lower division of the Aturian (Upper Senonian), is thought to correspond approximately to the Pierre shale and the Fox Hills sandstone of the United States. The Maestrichtian, which constitutes the upper division of the Aturian (Upper Senonian), together with the Danian, corresponds to the Laramie, at least in position. The Maestrichtian is abundantly plant-bearing at a number of localities, especially in the Münster Basin of Westphalia. The plants from these localities—Sendenhorst, Haldene, Lunfüde, etc.—were studied and described specially by Hosius[18] and by Hosius and Von der Marck.[19]

E. W. Berry,[20] in a chapter on the Upper Cretaceous floras of the world, has compiled a complete list of the Maestrichtian flora of the Münster Basin, which is as follows:

Apocynophyllum cuneatum Hosius and Von der Marck.
Apocynophyllum subrepandum Von der Marck.
Aralia denticulata Hosius and Von der Marck.
Cf. Ceanothus sp.
Chondrites furcilentus latior Von der Marck.
Chondrites intricatus Sternberg.
Chondrites jungiformis Debey and Ettingshausen.
Chondrites polymorphus Hosius and Von der Marck.
Chondrites subcurvatus Hosius and Von der Marck.
Comptonia tenera Hosius and Von der Marck.
Cunninghamites elegans (Corda) Endlicher.
Cunninghamites squamosus Heer.
Dewalquea gelindensis Saporta and Marion.
Dewalquea haldemiana Saporta and Marion.
Dewalquea haldemiana angustifolia Hosius and Von der Marck.
Dewalquea haldemiana latifolia Hosius and Von der Marck.
Dewalquea insignis Hosius and Von der Marck.
Dryandroides haldemiana Hosius and Von der Marck.
Dryandroides macrophylla Hosius and Von der Marck.
Eolirion? nervosum Hosius and Von der Marck.
Eolirion primigenum Schenck?
Eolirion? subfalcatum Hosius and Von der Marck.
Eucalyptus haldemiana Debey.
Eucalyptus inaequilatera Von der Marck.
Ficus angulata Hosius and Von der Marck.
Ficus densinervis Hosius and Von der Marck.
Ficus laurifolia Hosius and Von der Marck.
Frenelopsis königii Hosius and Von der Marck.
Haliserites contortuplicatus Von der Marck.
Laurus affinis Hosius and Von der Marck.
Myrica leiophylla Hosius and Von der Marck.
Myrica primaeva Hosius and Von der Marck.
Cf. Myrtophyllum cryptoneuron Saporta and Marion.
Nerium röhlii Von der Marck.
Cf. Oreodaphne apicifolia Saporta and Marion.
Osmunda haldemiana Hosius and Von der Marck.
Pinus monasteriensis Hosius and Von der Marck.
Populus tremulaeformis Hosius and Von der Marck.
Pisidonia cretacea Hosius and Von der Marck.
Quercus asymetia Hosius and Von der Marck.

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[17] Berry, E. W., Maryland Geol. Survey, Upper Cretaceous, p. 196, 1916.

[18] Hosius, A., Die in der Westfälischen Kreideformation vorkommen den Pflanzenreste Münster, pp. 1-34, 1869: Ueber einige Dicotyledonen der Westfälischen Kreideformation: Palaeontographica, vol. 17, pp. 83-104, pls. 12-17, 1869.

[19] Hosius, A., and Von der Marck, Die flora der Westfälischen Kreideformation: Palaeontographica, vol. 26, pp. 125-256, pls. 24-44, 1880.

[20] Maryland Geol. Survey, Upper Cretaceous, p. 283, 1916.

Quercus castanoides Hosius and Von der Marck.
Quercus dryandraefolia Von der Marck.
Quercus euryphylla Hosius and Von der Marck.
Quercus formosa Hosius and Von der Marck.
Quercus heiracifolia Hosius and Von der Marck.
Quercus iliciformis Hosius and Von der Marck.
Quercus rhomboidalis Hosius and Von der Marck.
Quercus sphenobasis Hosius and Von der Marck.
Quercus westfalica latior Hosius and Von der Marck.
Quercus westfalica oblongata Hosius and Von der Marck.
Quercus westfalica obtusata Hosius and Von der Marck.
Cf. Rhamnus sp.
Sequoia reichenbachi (Geinitz) Heer.
Taenidium alysoides Hosius and Von der Marck.
Tetraphyllum dubium Hosius and Von der Marck.
Thalassocharis westfalica Hosius and Von der Marck.

This flora comprises 56 forms, only one of which, *Sequoia reichenbachi*, is found in the Laramie. This is without special significance, for this species enjoys a world-wide distribution and ranges in age from Jurassic to uppermost Cretaceous. A number of genera, such as *Ficus*, *Laurus*, *Myrica*, *Populus*, and *Quercus*, are common to the two, but the species are all perfectly distinct and apparently unrelated. It appears to the writer that the Maestrichtian flora is much more closely related to the Montana flora. This is especially shown by the common presence of certain conifers, such as *Cunninghamites*, *Frenelopsis*, and *Sequoia reichenbachi*. Be this as it may, the Maestrichtian certainly has no particular relationship with the flora of the Laramie.

THE FLORA.

Phylum THALLOPHYTA.

Delesseria fulva Lesquereux.

Plate I, figure 4 (type).

Delesseria fulva Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1872, p. 376, 1873; idem for 1873, p. 379, 1874; idem for 1876, p. 496, 1878; Tertiary flora: U. S. Geol. Survey Terr. Rept., vol. 7, p. 39, pl. 1, fig. 10, 1878. [Lesquereux's original figure of the type is here reproduced.]

The type of this species is No. 9 of the United States National Museum collection of fossil plants and appears to be the only example ever obtained. It is preserved on a fine-grained hard white sandstone, on which it stands out in bold relief, being itself of a reddish-brown color.

Occurrence: Laramie formation, Golden, Colo., under or between coal beds.

Phylum PTERIDOPHYTA.

Order FILICALES.

Family POLYPODIACEÆ.

Onoclea fecunda (Lesquereux) Knowlton.

Plate I, figures 2, 3.

Caulinites fecundus Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1872, p. 384, 1873; idem for 1873, p. 380, 1874; idem for 1876, p. 501, 1878; Tertiary flora: U. S. Geol. Survey Terr. Rept., vol. 7, p. 101, pl. 14, figs. 1-3, 1878. [Lesquereux's original figures are here reproduced.]

Onoclea fecunda (Lesquereux) Knowlton, U. S. Geol. Survey Bull. 152, p. 153, 1898.

Fertile frond contracted, closely pinnate; main rachis broad (2 millimeters), smooth, divided into opposite erect branches which bear on each side thickly set short-pediceled simple spherical "capsules" (sporangia); sterile portion not known.

The type specimens of this plant are preserved in the United States National Museum (Nos. 120, 121). Their original reference to the genus *Caulinites* was a matter of uncertainty, for Lesquereux in his first mention says,[21] "This relation to species of our time is unknown," and later [22] adds:

> It is very questionable if these fine fruiting branches may be referred to this genus. They have this in common only—a monospermous (?) nucula with a cellulose envelope. As I have been unable to find either in the fossil species described until now or in the collection of living plants which I was able to consult anything to which they had apparent relation, I have left them in this as yet vaguely defined genus.

No additional material has been obtained since that described by Lesquereux, and it is perhaps hazardous to transfer these specimens to another genus, but all things being taken into account, the suggestion of the late Joseph F. James [23] that they closely resemble the fruiting frond of the living *Onoclea sensibilis* seems to justify the change. When the fossil and living plants are placed side by side it is seen that the resemblance is striking and suggestive. The fossil has the same pinnate branching and opposite, contiguous, short-pediceled "capsules" as the living species. The living form, as is well known, has the fertile pinnules rolled up into berry-like bodies, on the outside of which thick veins are very prominent. In the fossil this feature is apparently absent. Considering the fact that this fruiting portion has been found only once, it is not strange that the sterile portion remains unknown.

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[21] U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1872, p. 384, 1873.

[22] The Tertiary flora: U. S. Geol. Survey Terr. Rept., vol. 7, p. 101, 1878.

[23] Science, vol. 3, p. 433, fig. 1a, 1884.

A species that has a somewhat similar history has been found in the Raritan and Magothy formations of southern New York and the islands south of the New England mainland. It was first described as *Caulinites inquirendus* Hollick[24] and later transferred to *Onoclea*[25] on the ground of its resemblance to the species under consideration. Like our form, it has pinnately arranged branches with the spheroidal "capsules" in a single row on each side, and associated sterile fronds have not been found with it.

One of the most abundant and widely distributed plants of the Fort Union formation is a fern that can not be distinguished from the living sensitive fern, *Onoclea sensibilis*. It occurs at some localities by hundreds, but in only one known place in all the vast area covered by the Fort Union formation has it been found fruiting. In a small collection obtained near Porcupine Butte, Sweetgrass County, Mont., there were many of the usual sterile fragments, and associated with them a few fertile fronds.[26] A comparison of these fertile fronds with the Laramie specimens under consideration shows a close, at least generic similarity.

Thus, as at present provisionally marked out, our knowledge of the geologic history of the living sensitive fern may stand as follows:

Onoclea inquirenda Hollick.....	Raritan.
Onoclea neo-mexicana Knowlton.	Montana.
Onoclea fecunda (Lesquereux) Knowlton.	Laramie.
Onoclea sensibilis fossilis Newberry.	Fort Union.
Onoclea sensibilis Linné........	Living.

Occurrence: Laramie formation, Erie, Boulder County, Colo., collected by Leo Lesquereux about 1872.

Dryopteris georgei Knowlton, n. sp.

Plate I, figures 6, 7.

Fronds probably of large size but the complete outline unknown, though apparently it was at least thrice pinnatified; main rachis not sure; secondary rachis strong, straight, grooved; pinnae apparently lanceolate; pinnules numerous, very close, alternate or subopposite, narrowly linear-lanceolate, sessile, narrowly acuminate at apex, cut into numerous small, oblong, rather obtuse lobes, the cutting being made less toward the apex; nervation fairly strong, consisting of a stout midvein and five or six pairs of once-forked veins; fruit not seen.

This fine species, which I am able to include by the courtesy of Prof. R. D. George, of the University of Colorado, is all that has been found, and although a considerable portion of the frond is preserved it was evidently of much larger size when perfect. Two of the pinnae are parallel and lie in such a position as to suggest that they were attached to a common rachis, in which case the whole frond must have been of imposing appearance. The pinnae appear to have been 15 or 20 centimeters in length and 7 or 8 centimeters in width. The pinnules, as already noted, are narrowly linear-lanceolate, their length being 4 or 5 centimeters and their width about 1 centimeter at base; they begin to narrow near the middle and become narrowly acuminate at the apex.

The coriaceous appearance of the frond and its rather strict aspect suggest the probability that it was of xerophytic habit.

The photograph showing the whole frond somewhat less than natural size was sent by Prof. George, who also kindly donated the two fragments of the counterpart shown in figures 6 and 7.

Occurrence: Laramie formation, shaft of Columbia mine, 150 feet from the surface, near Louisville Junction, Boulder County, Colo., submitted by R. D. George. Type specimen in the Museum of the University of Colorado. Boulder, Colo.; pieces of counterpart in United States National Museum.

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[24] Hollick, Arthur, New York Bot. Gard. Bull., vol. 3, p. 40[illegible], pl. 20, fig. 3, 1904.

[25] Hollick, Arthur, U. S. Geol. Survey Mon. 50, p. 32, pl. 1, figs. 1-7, 1906.

[26] Knowlton, F. H., Torrey Bot. Club Bull., vol. 29, p. 705, p. 26, figs. 1-4. 1902.

Dryopteris laramiensis Knowlton.

Plate I, figure 5 (type).

Dryopteris laramiensis Knowlton, U. S. Geol. Survey Bull. 696, p. 248, 1919.

Lastrea (*Goniopteris*) *intermedia* Lesquereux, Tertiary flora: U. S. Geol. Survey Terr. Rept., vol. 7, p. 56, pl. 4, fig. 14, 1878. [Lesquereux's original figure is here reproduced.]

Aspidium (*Lastrea*) *pulchellum?* Heer, or *A. fischeri?* Heer. Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1870, p. 384, 1872.

This species is evidently very closely related to *Dryopteris lesquereuxii*, from which it appears to differ in having the pinnae closer, at a more acute angle of insertion on the rachis, and with the pinnules or lobes somewhat longer. Neither of these differences is of much importance, and it is quite possible that a series of specimens, if they were available, would show the two forms as merging, but so far as known the specimen figured by Lesquereux is the only specimen extant, and if it were not for some phases of the earlier history of the present "species," it would perhaps do no great harm to combine them. The specimens on which Lesquereux founded *Lastrea intermedia* are involved in some complications. In the first mention [27] (under the designation *Aspidium pulchellum* Heer, or *A. fischeri* Heer) they are said by Lesquereux to have come from "Muddy Creek," without mention of the State or other more exact location. From Hayden's itinerary, which precedes the report on the fossil plants, it appears reasonably certain that they must have come from the Muddy Creek that rises in Bridgers Pass, in the mountains south of Rawlins, in Carbon County, Wyo., and flows into Little Snake River. At a point in the valley of this stream near Barrel Springs Hayden [28] found, in addition to shells, remains of turtles, fish, etc., "a few obscure plants, like blades of grass, stems of rushes, etc., in the clays; still higher up on the tops of the hills that border the stream are some thin, chalky clays crowded full of plants, as ferns, rushes, grasses, palms, etc., finely preserved." It is doubtful if any of this material is present in the collections of the United States National Museum, at least under this designation.

In the next mention of *Lastrea intermedia* by Lesquereux [29] it is said to have come from "Henrys Fork, a mixed lot." It is easy to see how this mistake arose, for in the Annual Report for 1870, page 384, the designation "Henrys Fork" occurs at the top of the page, while that of "Muddy Creek" is in the middle of the page without indention or other display and so is easily overlooked. But this error is apparently responsible for Lesquereux's reference of *Lastrea intermedia* to the Green River formation,[30] which would doubtless be correct if it had actually come from Henrys Fork. There seems, therefore, absolutely no warrant for Henrys Fork as a locality or Green River formation as a horizon for this species.

Golden, Colo., is also given by Lesquereux [31] as a locality for "*Lastrea intermedia*," and the only specimen figured is preserved in the United States National Museum. It is preserved on the hard white sandstone characteristic of the Laramie at this locality and is apparently correctly recorded.

Owing to the absence of all specimens, except the one from the Laramie at Golden, the occurrence of this form in Wyoming will have to be ignored, at least until more material has been procured.

Occurrence: Laramie formation, Golden, Colo.

Dryopteris lesquereuxii Knowlton.

Aspidium goldianum Lesquereux,[32] U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1873, p. 393, 1874.

Lastrea (*Goniopteris*) *goldiana* Lesquereux, Tertiary flora: U. S. Geol. Survey Terr. Rept., vol. 7, p. 56, pl. 4, fig. 13, 1878.

Dryopteris lesquereuxii Knowlton, U. S. Geol. Survey Bull. 696, p. 248, 1919.

Frond bipinnate (tripinnate?), broadly deltoid in outline; pinnae linear, alternate, parallel, at an obtuse or rarely somewhat acute angle of divergence (40°–50°), alternately and equally pinnately lobed; lobes cut or separated by two-thirds or three-fourths of their length, oblong-lanceolate, obtusely pointed, inclined outside; middle nerve strong, distinct, lateral veins five to seven pairs, curving slightly upward, simple, parallel.

The ferns first described by Lesquereux under the name *Aspidium goldianum* appear

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[27] U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1870, p. 384, 1872.

[28] Idem, p. 73.

[29] The Tertiary flora: U. S. Geol. Survey Terr. Rept., vol. 7, p. 56, 1878

[30] The Cretaceous and Tertiary floras: U. S. Geol. Survey Terr. Rept., vol. 8, p. 138, 1883.

[31] Op. cit. (Tertiary flora), p. 57, pl. 4, fig. 14.

[32] This name was preoccupied by the living *Aspidium goldianum* Hooker, 1824, now *Dryopteris goldiana* (Hooker) A. Gray, 1848. I have therefore given the fossil form a new name in honor of its describer.

to be very well characterized, being bipinnate, or perhaps it would be better to say bipinnatified, with the pinnae alternate, at a low angle of divergence with the main rachis, and lanceolate in general outline. They are cut nearly to the secondary rachis, with numerous linear-lanceolate, rather obtuse segments. In the type species figured in the "Tertiary flora" (pl. 4, fig. 13) the segments of the pinnae are short, being from 7 to 9 millimeters in length, and have from five to seven pairs of simple nerves.

The type of *Aspidium goldianum* Lesquereux (now *Dryopteris lesquereuxii*) is said to have come from Golden, Colo., and an examination of the specimen (No. 26, U. S. Nat. Mus.) appears to confirm this statement; in any event there is no tangible evidence to the contrary. The species has not been noted in any of the recent collections from Golden.

Occurrence: Laramie formation, Golden, Colo.

Dryopteris? carbonensis Knowlton, n. sp.

Plate XX, figures 3–5.

Dryopteris? carbonensis Knowlton [nomen nudum], U. S. Geol. Survey Bull. 696, p. 249, 1919.

Fronds once pinnate (?); pinnae probably lanceolate, deeply pinnatified, the divisions nearly opposite, narrowly deltoid or broadly lanceolate in outline, with obtusely acuminate apex and perfectly entire margins; secondary rachis strong; midnerve of segments thin, practically straight; nerves obscure, apparently remote and simple; fruit unknown.

This species is based on the three fragments figured and is apparently quite distinct from anything from the true Laramie heretofore described. Whether it belongs to the genus *Dryopteris* is not by any means certain, for without fruit that point can not be positively ascertained, but from its general resemblance to certain species of this genus I have decided so to refer it. It is, for example, quite like some of the larger pinnae of *Dryopteris goldiana* (Hooker), a living species of eastern North America.

From its general resemblance to the above-mentioned living species, I have assumed that it had once-pinnate fronds with numerous lanceolate pinnae, but this, of course, is largely conjecture. The divisions of the pinnae are cut a little more than half the distance to the midvein. They are slightly scythe-shaped and have rather acute apices. The secondary nerves of the divisions appear to be simple, but the specimens are preserved on a rather coarse grained matrix which is not well suited to preserve the finer nervation, and it is impossible to say whether they were forked or not. No trace of the fructification is preserved.

A single fragment of this species is found also in the collections from Marshall, Colo.; it is without nervation and is on the same piece of rock with *Ficus arenacea*.

Occurrence: Laramie formation, Mount Carbon, Morrison, Colo.; sandstone near coal seam, Marshall, Colo.; collected by A. Lakes, 1890.

Genus PHANEROPHLEBITES Knowlton, n. gen.

Of the general type of the living *Phanerophlebia*, but with thick, fleshy midrib, and few free veins.

Phanerophlebites pealei Knowlton, n. sp.

Plate III, figure 5.

Phanerophlebites pealei Knowlton [nomen nudum], U. S. Geol. Survey Bull. 696, p. 439, 1919.

Outline of whole frond not known but presumably pinnate, pinnae large, strap-shaped, with apparently entire margins; midrib extremely thick and fleshy; nerves numerous, rather fine, usually forking near the midrib and once or twice before reaching the margin, sometimes free but usually anastomosing; fruit not preserved.

This form is represented only by the example here figured, and this is more or less fragmentary, neither base nor apex being retained. It is now about 12 centimeters long but was obviously very much longer when perfect. The width was 4.5 or 5 centimeters. The small portion of the margin preserved shows it to be entire or perhaps slightly undulate. This pinna was evidently of thick substance, as indicated by the very strong midrib and the immersed appearance of the veins. The veins are fine and very close and are more or less conspicuously anastomosed. All the veins fork, and some of them appear to be free, but this feature, owing to the small amount of material, is difficult to make out.

It is with some hesitation that this fragmentary specimen is described as establishing a new genus. It is aspidioid in general appearance and seems to approach most closely the living genus *Phanerophlebia*. This genus embraces about a dozen rather closely related species extending from the southern border of the United States through Mexico and Central America to Brazil. In some ways the specimen approaches most closely *Phanerophlebia nobilis* (Schlechtendal and Chamisso) Presl, a native of Mexico, especially in type of nervation.

Occurrence: Laramie formation, Lafayette, Colo., dump of Simpson mine, collected by A. C. Peale, for whom the species is named.

Asplenium martini Knowlton, n. sp.

Plate II, figure 6.

Asplenium martini Knowlton [nomen nudum], U. S. Geol. Survey Bull. 696, p. 105, 1919.

Outline of whole frond unknown but at least thrice-pinnatified, apparently thick or coriaceous in texture; pinnae long-lanceolate, with an exceedingly strong rachis, cut with numerous opposite or subopposite, short, ovate or ovate-oblong, obtuse pinnules; nervation of pinnules strong, consisting of a very strong midvein and 8 or 10 pairs of strong veins, which are once-forked, usually near the base; fruit not seen.

This form is so fragmentary as hardly to be worthy of characterization, yet even these small pieces show clearly that it must have been a plant of striking appearance. The fragment is about 8 centimeters in length, and to judge from the very thick rachis it must have been when perfect at least twice this length and was probably even larger. The rachis is fully 2 millimeters thick. Only one pinnule is anywhere near perfect. This is nearly 2 centimeters in length and is about 12 millimeters broad. The pinnules, so far as can be ascertained, were opposite or subopposite and cut by a sharp sinus within 4 or 5 millimeters of the rachis. The nervation of the pinnules, as already indicated, is very deeply impressed, showing that the texture was thick and probably coriaceous. The strong midvein is slightly irregular, and the nerves, also very strong, are once-forked, usually near the midvein.

In the absence of fruit it is impossible to be certain of the generic reference, but the form is so distinct, even in the fragments available, that it must constitute a good horizon marker. Among fossil species it is suggestive of *Asplenium magnum* Knowlton,[33] from the Fort Union of the Yellowstone National Park, but it differs in a number of important particulars. It is much larger than *Asplenium magnum*, being in fact nearly as large as the enlargement of that species shown in figure 8a of the plate above cited. Its pinnules are more deeply cut, and the nervation is very much stronger, though of the same type.

In some respects it is closer to *Asplenium coloradense* Knowlton,[34] from the Vermejo formation of the Raton Mesa region, which was at first identified by Hollick [35] with *Asplenium magnum*. The form under consideration seems to differ from *Asplenium coloradense* in its larger size, more obtuse pinnules, and much stronger nervation. A series of specimens showing the variation in size might bring them together, but for the present they are best kept apart, though obviously closely related.

This species is named in honor of George C. Martin, of the United States Geological Survey, who assisted in making the collection of which it is a part.

Occurrence: Laramie formation, dump of Reliance mine, 1¾ miles northeast of Erie, Colo., collected by F. H. Knowlton and G. C. Martin.

Pteris goldmani Knowlton, n. sp.

Plate II, figure 3.

Pteris goldmani Knowlton [nomen nudum], U. S. Geol. Survey Bull. 696, p. 518, 1919.

Outline of frond unknown; pinnae lanceolate, margin entire; rachis thin, grooved; nerves numerous, at an angle of 50° or 60°, slightly curved, forking a short distance above the base and again below the margin, often anastomosing.

Although this is a mere fragment 3 centimeters long and the same in width, it is so well characterized by the nervation that it seems worthy of full specific rank. It is of the type of what has been called *Pteris subsimplex* Lesquereux,[36] *Pteris erosa* Lesquereux,[37] *Pteris undulata* Lesquereux, etc., but differs essentially in having the nerves at a more acute angle and regularly twice-forked. The nerves are also frequently anastomosed, especially near the margin.

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[33] U. S. Geol. Survey Mon. 32, pt. 2, pl. 79, figs. 5–8, 1899.

[34] U. S. Geol. Survey Prof. Paper 101, pl. 1, figs. 1, 2, 1918.

[35] Hollick, Arthur, Torreya, vol. 2, p. 145, pl. 4, figs. 1, 2, 1902.

[36] Lesquereux, Leo, U. S. Geol. Survey Terr. Rept., vol. 7, pl. 4, figs. 5–7, 1878.

[37] Idem, fig. 8.

This species is named in honor of Marcus I. Goldman, of the United States Geological Survey, who assisted in making the collection at this locality.

Occurrence: Laramie formation, Popes Bluff, west of Pikeview, Colo. (sec. 14, T. 13 S., R. 67 W.), collected by A. C. Peale and M. I. Goldman, 1908.

Pteris? sp.

Plate II, figure 5.

Pteris? sp. Knowlton [nomen], U. S. Geol. Survey Bull. 696, p. 513, 1919.

The specimen here figured is so small a fragment that were it not for the fact that it is very different from anything heretofore found in the Laramie, it would hardly be worthy of mention. It is the wedge-shaped basal portion of what was apparently a large lanceolate frond or pinnule. The midrib was exceedingly thick, and the blade appears also to have been thick or coriaceous. The nerves are very fine, close, parallel, and at a low angle of emergence. It is difficult to ascertain whether the veins fork at the extreme base or are simple, though presumably they are forked just above their point of origin. Occasionally a vein may be observed to fork near the middle, but beyond this little can be made out.

This fragment is so small and obscure that comparisons with other forms are hardly warranted, though in passing it may be said that the specimen somewhat resembles what Lesquereux described as *Gymnogramma gardneri*,[38] especially in the shape of the base and the thick midrib, but it differs strongly in the more numerous finer veins, which do not anastomose.

Occurrence: Laramie formation, Marshall, Colo., wooded bluff just south of station, at the highest plant-bearing point in the section, collected by A. C. Peale.

Family SCHIZAEACEAE.

Anemia elongata (Newberry) Knowlton.

Plate II, figure 2.

Anemia elongata (Newberry) Knowlton, U. S. Geol. Survey Bull. 696, p. 74, 1919.

Sphenopteris (*Asplenium*) *elongatum* Newberry, Boston Soc. Nat. Hist. Jour., vol. 7, p. 511, 1863.

Anemia subcretacea? (Saporta) Gardner and Ettingshausen, British Eocene flora, vol. 1, Filices, pt. 2, p. 45, pls. 8, 9, 1880.

Knowlton, U. S. Geol. Survey Bull. 152, p. 34, 1898; Mon. 32, pt. 2, p. 657, 1899; Bull. 163, p. 20, 1900.

Anemia perplexa Hollick, in Newberry, U. S. Geol. Survey Mon. 35, p. 3, pl. 15, figs. 1, 1a, 1898.

Gymnogramma haydenii Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1872, p. 295, 1873; Tertiary flora: U. S. Geol. Survey Terr. Rept., vol. 7, p. 59, pl. 4, figs. 1–3, 1878.

Anemia haydenii (Lesquereux) Cockerell, Torreya, vol. 9, p. 142, 1909.

My understanding of the status of the American material usually referred to *Anemia subcretacea* is set forth at length in my "Flora of of the Montana formation,"[39] and I have little or nothing to add to that account. One difficulty in the study of ferns of this group is lack of sufficient material, for somehow it happens that although *Anemia* is fairly well distributed both geologically and geographically, it is rarely found abundant or well preserved. The type specimens of Lesquereux's *Gymnogramma haydenii*, for instance, are mere fragments that can give only a partial idea of its size and appearance. The example here figured, although exceptionally well preserved, is the only one present in the collections from Erie. It is almost entire in the upper portion and sparingly toothed below, but otherwise it is very much like the figures of *Gymnogramma haydenii*. It is rather more robust than the figures of the English species shown by Gardner and Ettingshausen would imply, though it approaches that species most closely. I have questioned the reference of the Erie specimen to *Anemia subcretacea* rather than make a new species. If additional material can be procured it may serve to settle the status of this form.

Occurrence: Laramie formation, ?Erie, Colo.; Mesaverde, ?Point of Rocks, Wyo.; Puget group, ?Washington.

Anemia supercretacea Hollick.

Anemia supercretacea Hollick, Torreya, vol. 2, p. 145, pl. 3, figs. 6, 7, 1902.

Cockerell, Torreya, vol. 9, p.142, 1909.

This species was described by Hollick from material collected in the well-known reddish sandstone at Florence, Colo., from beds then supposed to be of Laramie age but subsequently determined to belong to the Vermejo formation of the Montana group. It is recorded from the Laramie at Marshall, Colo., by Cockerell, who says:

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[38] Lesquereux, Leo, U. S. Geol. Survey Terr. Rept., vol. 7, pl. 4 fig. 2, 1878.

[39] Knowlton, F. H., U. S. Geol. Survey Bull. 163, pp. 20-22, 1900.

> Found first at Marshall by Paul Haworth. Our specimens run a little larger than Hollick's but appear to be otherwise quite identical; the pinnules are entire. The plant may possibly be a variety of *Anemia haydenii* (*Gymnogramma haydenii* Lesquereux, 1872), which appears to be distinctly different from *A. subcretacea* (Saporta) Gardner and Ettingshausen as originally figured by Saporta.

I have not seen the material mentioned by Cockerell, nor has *Anemia* been noted in any of the collections from Marshall and vicinity that have passed through my hands, though I have no reason to doubt the above determination.

Occurrence: Vermejo formation, Florence, Colo. (type); Laramie formation, Marshall, Colo., reported by Prof. T. D. A. Cockerell.

Anemia sp.

Plate II, figure 1.

Anemia sp. Knowlton [nomen], U. S. Geol. Survey Bull. 696, p. 75, 1919.

In the material from a locality a few miles north of Colorado Springs there is a single fragment of the pinnule of an *Anemia*. The matrix on which it is preserved is so coarse grained that only the outline can be made out with certainty. The nervation appears to consist of slender veins at a rather acute angle, but their manner of forking can not be seen.

This fragment is very readily comparable with various species of *Anemia*, especially *Anemia subcretacea*, but it is so poorly preserved and so small that it is best left without speculation as to its specific identification.

Occurrence: Laramie formation, opposite sand-lime brick works about 4 miles north of Colorado Springs, Colo., collected by A. C. Peale and G. I. Finlay, 1908.

Lygodium? compactum Lesquereux.

Plate I, figure 1 (type).

Lygodium compactum Lesquereux, Am. Jour. Sci., 2d ser., vol. 16, p. 206, 1868; U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1869, p. 196 [reprint, 1875]; idem for 1873, p. 380, 1874; idem for 1876, p. 498, 1878; Tertiary flora: U. S. Geol. Survey Terr. Rept., vol. 7, p. 64, pl. 5, fig. 9, 1878. [Lesquereux's figure of the type is here reproduced.]

The type and so far as known the only specimen ever obtained of this species is No. 118 of the fossil-plant collections of the United States National Museum. It is a small fragment preserved on a piece of hard, rather coarse-grained sandstone, and is very obscure.

There is much uncertainty as to the proper disposition of this specimen. It is so fragmentary and its nervation is so poorly preserved that a satisfactory characterization of it is impossible. There is even some doubt as to whether it is a fern. But in the absence of additional specimens or further information concerning the type, it is retained as left by its author, in the hope that future exploration may clear up its position, though at present it is not of much value.

Occurrence: Laramie formation, Marshall mine, Marshall, Colo., original collection of F. V. Hayden.

Order EQUISETALES.

Family EQUISETACEAE.

Equisetum perlaevigatum Cockerell.

Plate I, figures 8, 9.

Equisetum perlaevigatum Cockerell, West Am. Scientist, vol. 6, p. 154, 1889.

Equisetum laevigatum Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1873, p. 395, 1874; idem for 1876, p. 498, 1878; Tertiary flora: U. S. Geol. Survey Terr. Rept., vol. 7, p. 68, pl. 6, figs. 6, 7, 1878. [Lesquereux's original figures are here reproduced.] [Homonym, Al. Braun, 1867.]

This so-called species is a very unsatisfactory one indeed. The material upon which it is founded is preserved in the United States National Museum (Nos. 42, 43) and represents, so far as known, all that has ever been found. The larger specimen (original of Lesquereux's fig. 7), from Sand Creek, Colo., is very obscure and has more the appearance of a piece of dicotyledonous bark, or the impression of a stem. Its surface is wrinkled irregularly rather than striately, and the so-called tubercles can hardly be made out. As a factor in the distribution of the species this specimen can safely be ignored.

The smaller specimen (original of Lesquereux's fig. 6), from the hard white sandstone at Golden, Colo., is without doubt a portion of the underground stem of an *Equisetum*, but it could probably not be distinguished from certain other described species, and the advisability of retaining it is open to question. It is permitted to stand simply for the purpose of showing that the horsetails were present in these beds, though it may be but poorly characterized.

Occurrence: Laramie formation, Golden, Colo., original Museum collections.

Phylum SPERMATOPHYTA.

Class GYMNOSPERMAE.

Order CONIFERALES.

Family ARAUCARIACEAE.

Dammara sp.

Plate II, figure 4.

Dammara sp. Knowlton [nomen], U. S. Geol. Survey Bull. 696, p. 228, 1919.

In the collection from the wooded bluff south of Marshall, Colo., there is a single fragmentary scale that appears to be a *Dammara*. It is about 13 millimeters long and some 8 millimeters wide at the broadest point; it is strongly ribbed. The apical portion is broken away, so it is impossible to observe the spine of the scale, if there was one. The specimen is so fragmentary that it is hardly worth while to institute any comparisons with published forms. It was found in the association with *Rhamnus salicifolius*, *Rhamnus goldianus?*, and the fragment of a fern described as *Pteris?* sp.

Occurrence: Laramie formation, Marshall, Colo., wooded bluff just south of station, highest point in section, collected by A. C. Peale.

Family TAXODIACEAE.

Sequoia acuminata? Lesquereux.

Plate II, figures 7, 8.

Sequoia acuminata Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1874, p. 310, 1875; idem for 1876, p. 500, 1878; idem, Bull., vol. 1, No. 5, 2d ser., p. 384, 1876; Tertiary flora: U. S. Geol. Survey Terr. Rept., vol. 7, p. 80, pl. 7, figs. 15–16a, 1878.

The type specimens of this species are supposed to be preserved in the United States National Museum (No. 62), but they can not now be found. So far as can be made out from the figures it seems to be very close to *Sequoia longifolia* Lesquereux, a fact which Lesquereux recognized, as he says:

> This species differs from the former by the proportionally narrower leaves, with a very distinct middle nerve, and smooth surfaces; also by the stem, which is striate when decorticated. * * * The average size of the leaves is about the same in both forms, the leaves varying from 3 to 6 centimeters long and from 2 to 5 millimeters broad.

In the collection from Cowan station there is a single fragment that may belong to this species, but it is so fragmentary that the essential characters can not be made out with certainty.

The two examples figured, though fragmentary and not well preserved, appear to agree in all essential features with the specimens figured by Lesquereux.

Occurrence: Post-Laramie, Black Buttes, Wyo. (types). Laramie formation,? Cowan station, 10 miles south of Denver, Colo., collected by F. H. Knowlton; cut on Moffat railroad (Denver & Salt Lake) near Leyden Gulch, Colo., collected by A. C. Peale. Dawson arkose, Templeton Gap, 4 miles northeast of Colorado Springs, Colo., collected by A. C. Peale, 1908.

Sequoia reichenbachi (Geinitz) Heer.

Plate XX, figures 1, 2.

Araucarites reichenbachi Geinitz, Charakteristik der Schichten und Petrefacten des sächsisch-böhmischen Kreidegebirges, pt. 3, p. 98, pl. 24, fig. 4, 1842.

Sequoia reichenbachi (Geinitz) Heer, Flora fossilis arctica, vol. 1, p. 83, pl. 43, figs. 1d, 2b, 5a, 1868.

Lesquereux, U. S. Geol. Survey Terr. Rept., vol. 6, p. 51, pl. 1, figs. 10–10b, 1874; U. S. Geol. Survey Mon. 17, p. 35, pl. 2, fig. 4, 1892.

Hollick, New York Acad. Sci. Trans., vol. 12, p. 30, pl. 1, fig. 18, 1892.

Fontaine, U. S. Geol. Survey Mon. 15, p. 243, pl. 118, figs. 1, 4; pl. 119, figs. 1–5; pl. 120, figs. 7, 8; pl. 122, fig. 2; pl. 167, fig. 5, 1889.

Dawson, Roy. Soc. Canada Trans., vol. 3, p. 21, 1882.

Newberry, U. S. Geol. Survey Mon. 26, p. 49, pl. 9, fig. 19, 1896.

Knowlton, U. S. Geol. Survey Mon. 32, pt. 2, p. 657, 1898.

In the collection from Coal Creek, Boulder County, Colo., there is a single specimen which I am unable to separate from many of the figures referred to *Sequoia reichenbachi*, and I have so regarded it. As may be noted in the figure (Pl. XX, fig. 1), it is a fairly well preserved specimen with a large main branch and several smaller branchlets bearing rather closely appressed, sharp-pointed leaves. It is, for example, hardly to be distinguished from figures of this species given by Velenovsky [40] from the Cretaceous of Bohemia. I also find in the old United States National Museum collections a single specimen, recorded under No. 865, which was collected at Coal Creek by George Hadden. It was not figured by Lesquereux and represents the impression of a fragment from a large branch. It is indistinguishable from figure 23 of Plate VII in Lesquereux's "Tertiary flora." [41]

Among the specimens collected by Arthur Lakes at Mount Carbon, Morrison, Colo., from the sandstone near the coal seam, are a number of rather poorly preserved but evidently large branches of a conifer that I am unable to distinguish from this species. By taking an impression in clay the original form of the branches is restored in a fairly satisfactory manner. The leaves are seen to be rather long, sharp pointed, and spreading, but with incurved tips.

The small collection made on Crow Creek, Colo., contains three rather poorly preserved specimens of conifers that appear to be referable to this species. They are long, slender twigs covered with short, appressed scalelike leaves and apparently additional more slender leaves. They are not well enough preserved to warrant a positive reference to this or any other species.

Occurrence: Laramie formation, Coal Creek, Boulder County, Colo., collected by N. L. Britton about 1884; Mount Carbon, Morrison Colo., collected by A. Lakes in 1890; Crow Creek about 25 miles northeast of Greeley, Colo., collected by F. H. Knowlton and T. W. Stanton, 1896. The last is questionable.

Sequoia longifolia Lesquereux.

Plate III, figure 3; Plate IV, figure 2.

Sequoia longifolia Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1874, p. 298, 1876; Tertiary flora: U. S. Geol. Survey Terr. Rept., vol. 7, p. 79, pl. 61, figs. 28, 29 [not pl. 7, figs. 14, 14a, which = *Sequoia magnifolia* Knowlton].

Geinitzia longifolia (Lesquereux) Knowlton, U. S. Geol. Survey Bull. 63, p. 28, 1900.

Cunninghamites? sp.? Knowlton, U. S. Geol. Survey Bull. 163, p. 29, pl. 5, fig. 3, 1900.

There appears to be some confusion regarding Lesquereux's *Sequoia longifolia*. So far as can be made out, Lesquereux had specimens of a long-leaved conifer from Black Buttes, Wyo., to which it is inferred he gave the manuscript name "*Sequoia longifolia*." Before this species was published, however, specimens thought to represent the same species were obtained from Point of Rocks, Wyo., and the name was first published in the Hayden Annual Report for 1874 (1876), page 298, under the designation "*Sequoia longifolia* Lesq., MSS." In explanation he adds: "This species was already described from Black Buttes specimens." I can not find that it was ever published in connection with the Black Buttes specimens, and it seems that when Lesquereux actually came to publishing a report on the Black Buttes material he changed the name of the long-leaved conifer common at that place to *Sequoia acuminata*.[42] It is certain that he nowhere definitely recorded *Sequoia longifolia* as coming from Black Buttes, nor has it since been found there.

If the above interpretation is correct, as it is believed to be, it establishes Point of Rocks, Wyo., as the type locality for *Sequoia longifolia* and excludes the species from Black Buttes. The type specimens are the originals of figures 28 and 29 of Plate LXI of the "Tertiary flora" and are Nos. 73 and 74, respectively, of the United States National Museum collections. This leaves the specimen figured under this name in Plate VII, figures 14, 14a, of the "Tertiary flora" still to be accounted for. It is said [43] to have come from the "Haley coal mine, 10 miles northeast of Greeley, Colo. (A. C. Peale)"; it is No. 61 of the United States National Museum collections. I was informed by Dr. Peale that this statement was in error, as he did not collect it and was never at this locality. Inasmuch as Lesquereux pointed out certain marked differences between the Point of Rocks and Greeley specimens and added, "It may be, therefore, that these specimens represent two different species," and in further consideration of the uncertainty regarding the so-called Greeley specimen, it is apparently justifiable to consider only the Point of

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[40] Velenovsky, Josef, Die Gymnospermen der böhmischen Kreideformation, pl. 9, figs. 12, 14, etc., 1885.

[41] U. S. Geol. Survey Terr. Rept., vol. 7, 1878.

[42] U. S. Geol. Survey Terr. Bull., vol. 1, No. 5, 2d ser., p. 384, 1876; U. S. Geol. Survey Terr. Rept., vol. 7, p. 80, 1878.

[43] Lesquereux, Leo, op. cit., p. 80.

Rocks specimens in the present comparisons and discussions. Additional specimens from Point of Rocks were procured by L. F. Ward in 1883,[44] but none have been found in or about the supposed Greeley locality.

In the light of material recently studied it now seems probable that the specimen from the North Fork of Dutton Creek, Laramie Plains, Wyo., which I figured and described under the name *Cunninghamites?* sp.,[45] should be referred to the present form. Although the full characters can not be made out, owing to poor preservation, the general appearance is the same as in many specimens that undoubtedly belong to *Sequoia longifolia*.

It was suggested by Schenk[46] a number of years ago that Lesquereux's *Sequoia longifolia* should be referred to the genus *Geinitzia*, and as cones had not been found at that time, I adopted the suggestion and in my "Flora of the Montana formation"[47] transferred it to this genus. Although cones have not been found in connection with these specimens, they have been found attached to specimens that are now described under the name *Sequoia magnifolia* Knowlton,[48] and as these two forms are undoubtedly congeneric it is best to refer them all to *Sequoia*.

The material from Marshall, Colo., includes several specimens of coniferous branches that are not to be distinguished from *Sequoia longifolia* as described and figured by Lesquereux from Point of Rocks, Wyo. One of the best of these branches is here figured. It is a thick branch 1 centimeter in diameter and about 15 centimeters long. The scars on the branch and the insertion of the long, slender, acuminate leaves are the same as shown in figure 29 of Plate LXI in the "Tertiary flora." The manner in which the leaves are matted together is also the same, and there can be no reasonable doubt of their identity with Lesquereux's species.

A single poorly preserved branchlet (shown in Pl. IV, fig. 2) from Cowan station, south of Denver, appears to belong to this species.

Occurrence: Mesaverde formation, Point of Rocks, Wyo. (type locality). Laramie formation, Marshall, Colo., railroad cut between old and new stations, collected by A. C. Peale, 1908; Cowan station, 10 miles south of Denver, Colo., collected by F. H. Knowlton, 1908.

Order CYCADALES.

Family CYCADACEAE.

Cycadeoidea mirabilis (Lesquereux) Ward.

Cycadeoidea mirabilis (Lesquereux) Ward, Biol. Soc. Washington Proc., vol. 11, p. 86, 1894.

Zamiostrobus mirabilis Lesquereux, U. S. Geol. and Geog. Survey Terr. Bull., vol. 1, No. 5, 2d ser., p. 383, 1876; idem, Ann. Rept. for 1874, p. 309, 1876; Tertiary flora: U. S. Geol. Survey Terr. Rept., vol. 7, p. 70, pl. 63, figs. 1-1d, 1878.

Nelumbium James, Science, vol. 3, p. 434, 1884.

Clathropodium mirabile (Lesquereux) Ward, Science, vol. 3, p. 532, 1884.

Cycadeoidea zamiostrobus Solms, Real. accad. sci. Ist. Bologna Mem., 5th ser., vol. 2, p. 210, 1892.

It is extremely doubtful whether this species should properly be included in this work, but I have given it the benefit of the doubt. It was found by F. V. Hayden lying on the surface of the ground near Golden, Colo., within the Laramie area, but it probably belonged to a more ancient formation, from which it had been transported. The microscopic appearance of this interesting species was well described and fairly well figured by Lesquereux, and the internal structure has been admirably worked out by Count Solms, to whom the cutting and study of the specimen was submitted. It is mentioned further by G. R. Wieland in his work on American fossil cycads.[49]

Occurrence: Laramie formation (?), near Golden, Colo.

Class ANGIOSPERMAE.

Subclass MONOCOTYLEDONAE.

Order GRAMINALES.

Family CYPERACEAE?

Cyperacites? hillsii Knowlton, n. sp.

Plate XX, figure 6.

Cyperacites? hillsii Knowlton [nomen nudum], U. S. Geol. Survey Bull. 696, p. 222, 1919.

Leaves flat, without keel; nerves numerous, parallel, 5 millimeters apart, with a single more delicate intermediate nerve between the principal ones.

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[44] Knowlton, F. H., U. S. Geol. Survey Bull. 163, p. 28, 1900.

[45] Idem, p. 29, pl. 5, fig. 3.

[46] Schenk, A., in Zittel, K. A., Handbuch der Palaeontologie, Abt. 2, pp. 301, 302, 1880.

[47] Knowlton, F. H., U. S. Geol. Survey Bull. 163, p. 28, 1900.

[48] Knowlton, F. H., The flora of the Fox Hills sandstone: U. S. Geol. Survey Prof. Paper 98, p. 88, pl. 15, figs. 1-3, 1916.

[49] Carnegie Inst. Washington Pub. 34, vol. 2, p. 109, pl. 1, figs. 1, 2, 1916.

The material upon which this form is based is in reality hardly sufficient for the proper characterization of a new species, but as it appears to differ from all other Laramie species already described it must receive a name. It is based on fragments of leaves 7 or 8 centimeters long and from 1 to 1.5 centimeters wide. They are marked by numerous parallel veins about 5 millimeters apart, with slender intermediate veins, one between every two of the stronger ones. It is named in honor of Mr. R. C. Hills, of Denver, Colo.

Occurrence: Laramie formation, Erie and Coal Creek, Colo.

Cyperacites? tessellatus Knowlton, n. sp.

Plate III, figures 1, 2.

Cyperacites? tessellatus Knowlton [nomen nudum], U. S. Geol. Survey Bull. 696, p. 222, 1919.

In the material from Popes Bluff, the locality earlier known as the Healey coal mine, there are several fragments of a large monocotyledonous leaf that is very strongly marked. Neither the length nor the width can be ascertained, though there are fragments 8 centimeters long and 5 or 6 centimeters wide. It is provided with strong, deeply impressed longitudinal veins which are a little less than 1 millimeter apart and without intermediate veins. It is, however, also provided with cross veins, which are nearly as deeply impressed as the others and cut the space between the veins into very regular rectangular areas about 1 millimeter long. This was evidently a thick, firm leaf, as the veins and cross veins are so deeply impressed.

The proper generic reference for this form is uncertain. Superficially it resembles *Zingiberites dubius* Lesquereux,[50] from the Denver formation, but it is excluded at once by the fact that the latter species has six or seven very thin veins between the strong veins. It also resembles certain leaves that have been referred to *Typha*, such as *Typha latissima* Heer,[51] but it is twice the width of even the largest leaves of that species and has three or four intermediate veins between the larger ones. The cross veins in *Typha* are very much like those in the present specimens, but none of the nervation is deeply impressed.

Occurrence: Laramie formation, Popes Bluff, west of Pikeview, Colo. (sec. 14, T. 13 S., R. 67 W.), collected by A. C. Peale and M. I. Goldman, 1908.

Cyperacites? sp.

Plate IV, figure 1.

Cyperacites? sp. Knowlton [nomen], U. S. Geol. Survey Bull. 696, p. 223, 1919.

The collections from Leyden Gulch contain a number of specimens that are somewhat difficult of interpretation, though obviously they are of monocotyledonous type. They appear to represent the stems and leaves of some plant resembling a sedge or possibly a grass. They are from 8 to 10 millimeters wide and nearly 1 millimeter in thickness as now compressed; what appear to be leaves of the same plant are 1.5 centimeters wide. They are provided with numerous very fine, close, parallel nerves, about 8 or 10 to each millimeter. There is a little evidence to show that some of the nerves are slightly heavier than the others, but the difference is not marked. There is also some evidence of the presence of cross veins, but this is very obscure.

This form is of no particular importance biologically and is described simply for the purpose of showing that certain plants of this general type were present at this time.

Occurrence: Laramie formation, Leyden Gulch, 6½ miles north of Golden, Colo., collected by A. C. Peale, 1908.

Family GRAMINEAE.

Phragmites laramianus Cockerell.

Phragmites laramianus Cockerell, Torreya, vol. 9, p. 141, 1909.

Phragmites oeningensis Al. Braun. Lesquereux, Tertiary flora: U. S. Geol. Survey Terr. Rept., vol. 7, p. 88, pl. 8, figs. 1, 2, 1878.

The specimens figured by Lesquereux in the "Tertiary flora" under the name *Phragmites oeningensis* are preserved in the collections of the United States National Museum (Nos. 93, 94). They came from Golden, Colo., the matrix on which they occur being the hard white sandstone characteristic of the Laramie at that locality. These specimens are before me and appear to have been fairly well figured and described. They are mere fragments,

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[50] Lesquereux, Leo, U. S. Geol. Survey Terr. Rept., vol. 7, p. 95, pl. 15, fig. 1, 1878.

[51] Heer, Oswald, Flora tertiaria Helvetiae, vol. 1, pls. 43, 44, 1855.

Juglans newberryi Knowlton, n. sp.

Plate XX, figures 8-10.

Juglans newberryi Knowlton [nomen nudum], U. S. Geol. Survey Bull. 696, p. 335, 1919.

Leaves or leaflets large, about 15 centimeters long and 4.5 or 5 centimeters wide, with entire margins; blade long, narrow, wedge-shaped and strongly inequilateral at base, rather long-acuminate at apex; midrib thick, strong; secondaries alternate, numerous (about 20 pairs), at an open angle, camptodrome, arching and joining just inside the borders, sometimes festooned outside the arches; intermediate secondaries numerous, often extending nearly to the margin; nervilles strong, mainly percurrent and oblique to the secondaries; reticulation obsolete.

This fine species is represented by four specimens, none of which, however, is preserved entire. Two of them have the bases preserved, one the apex, and the other represents a segment near the middle of the blade. They are rather long, narrow leaflets, strikingly inequilateral at the base and acuminate at the apex.

This species calls to mind a number of fossil forms, yet when carefully compared with them it is found to differ from all. It has, for example, much the shape and size of *Juglans denticulata* Heer, or *J. crossii* Knowlton, as it is now called,[56] which differs in having numerous sharp teeth. It also suggests certain of the narrower leaflets of *J. rugosa* Lesquereux,[57] which differs in general in being more or less heart-shaped at the base and in having fewer secondaries.

Juglans acuminata Al. Braun,[58] of the Swiss Miocene, which, by the way, it is almost impossible to distinguish from *J. rugosa*, has much the same nervation and size as *J. newberryi* but differs in shape. *Juglans californica* Lesquereux,[59] from the auriferous gravels of California, is not greatly unlike the form under discussion, differing in being obtuse at the apex and less unequal-sided at the base.

I have named this species in honor of the late Dr. J. S. Newberry, who did so much to develop the paleobotany of the Rocky Mountain region.

Occurrence: Laramie formation, Erie, Colo., collected by N. L. Britton about 1880.

Juglans laramiensis Knowlton, n. sp.

Plate XX, figure 12.

Juglans laramiensis .Knowlton [nomen nudum], U. S. Geol. Survey Bull. 696, p. 334, 1919.

Leaflets coriaceous, long and narrowly ovate-lanceolate, often slightly unequal-sided at the base, rather gradually narrowed from the widest point, which is about one-fourth the length of the blade, to the base and upward to the long, narrow acuminate apex; margin entire; nervation strongly and plainly marked, consisting of a rather strong, straight midrib and some 9 or 10 pairs of alternate or subopposite secondaries which arise at an angle, curve considerably upward, and disappear close to the margin or, especially in the upper part, join the secondary next above; nervilles numerous, strong, both percurrent and broken, inclining to be at right angles to the midrib on one side of the blade and to the secondaries on the other side; finer nervation not retained.

This strongly marked species is represented by several specimens, one of the best of which is figured. They are lanceolate or very narrowly ovate-lanceolate, with an obtusely wedge-shaped base and a long, gradually narrowed, sharp-pointed apex. The larger of these two examples is 9.5 centimeters in length and about 3 centimeters in width; the smaller is about 8 centimeters in length and 2.25 centimeters in width. The petiole is not preserved in either.

This species is very suggestive of *Juglans schimperi* Lesquereux,[60] from the Green River formation at Green River, Wyo. It is of practically the same shape and size but differs in having only 9 or 10 instead of some 18 pairs of secondaries, which are at a more acute angle and rather more arched upward, while the nervilles are stronger, more commonly percurrent, and at right angles to the midrib on one side.

In his treatment of *Juglans schimperi* in the "Tertiary flora" Lesquereux states[61] that the original of his Plate LVI, figure 9, came from Golden, Colo. This particular specimen is fortunately preserved in the United States

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[56] U. S. Geol. Survey Bull. 152, p. 122, 1898.

[57] U. S. Geol. Survey Terr. Rept., vol. 7, p. 286, pl. 55, figs. 1-9, 1878.

[58] Flora tertiaria Helvetiae, vol. 3, pl. 128, figs. 1-10.

[59] Harvard Coll. Mus. Comp. Zoology Mem., vol. 6, pl. 9, fig. 14, 1878.

[60] The Tertiary flora: U. S. Geol. Survey Terr. Rept., vol. 7, pl. 56, figs. 5-10, 1878.

[61] Idem, p. 288.

National Museum (No. 468), and in the catalogue of fossil plants it is recorded in Lesquereux's handwriting as having come from Green River, Wyo. The matrix is not that of Golden but agrees perfectly with the abundant material found above the fish beds at Green River, and there is consequently no reason for supposing that this species has ever been found in the Denver beds at Golden.

Occurrence: Laramie formation, Coal Creek, Boulder County, Colo., collected by N. L. Britton about 1880.

Juglans leconteana Lesquereux.

Plate VIII, figures 1–3 [types].

Juglans leconteana Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1870, p. 382, 1872; idem for 1876, p. 517; 1878; U. S. Geol. Survey Terr. Rept., vol. 7, p. 285, pl. 54, figs. 10–13. 1878 [figs. 10–12 here reproduced].

Friederich, Beiträge zur Kentniss der Tertiärflora von Sachsen, p. 150, pl. 19, fig. 7, 1883

This species is in much confusion. Three of the specimens figured in the "Tertiary flora" (figs. 10–12) are not now and have apparently never been in the collections of the United States National Museum. They came, according to Lesquereux, from the Marshall coal mine, in Boulder County, Colo., and are probably lost. The original of Lesquereux's figure 13 is the only one in the United States National Museum (No. 453). It is stated in the "Tertiary flora" to have come from Evanston, Wyo., but in the Museum catalogue it is recorded from Black Buttes, Wyo., in Lesquereux's handwriting. This last statement is probably correct, for the fossil is preserved in a fragment of the "red baked shale" so characteristic of the upper beds at this place.

In the annual report of the Hayden Survey for 1870, page 382, this species is recorded in a list of species found at Raton Pass, N. Mex., but the specimen or specimens upon which this statement is based has never been in the United States National Museum, and the reference may safely be dismissed as an error.

Lesquereux has also reported this species from Cherry Creek, Wasco County, Oreg., but there was only a single example, which I excluded from my flora of these beds[62] on the ground that it was so poorly preserved as to be impossible of determination.

Friederich has identified this species with a leaf from the lower Oligocene of Bornstedt, in Saxony, remarking at the same time that he was unable to draw any line between Lesquereux's *Juglans rugosa*, *J. rhamnoides*, and *J. leconteana*. He also adds that they might better be referred to *Diospyros*, a view which can hardly be accepted, for *J. rugosa* at least. Lesquereux himself acknowledges that it is hardly possible to distinguish this species from *J. rugosa*, yet he says:

> It differs by comparatively shorter, broader leaves, which are first rounded, then abruptly curved or narrowed to the short petiole; by the lateral nerves at a more acute angle of divergence (40°), passing nearly straight toward the borders, with thin simple bows nearer to them.

Although the differences are not great and might possibly break down with a larger series of specimens for comparison, I have decided to maintain this species as left by its author, especially as the types are nearly all lost, and no additional material is forthcoming.

Occurrence: Laramie formation, Marshall mine, Marshall, Boulder County, Colo. Post-Laramie (in my opinion), ?Black Buttes, Wyo. Evanston formation ?, ?Evanston, Wyo.

Juglans praerugosa Knowlton, n. sp.

Plate V, figure 2; Plate XXI, figure 5.

Juglans praerugosa Knowlton [nomen nudum], U. S. Geol. Survey Bull. 696, p. 396, 1916.

Juglans rugosa Lesquereux, Am. Jour. Sci., 2d ser. vol. 45, 1868; U. S. Geol. Survey Terr. Third Ann. Rept., p. 96, 1869 [reprint, p. 196, 1873].

Leaflets evidently rather thin in texture, ovate or ovate-elliptical, abruptly rounded to the truncate base (apex destroyed); margin entire; midrib slender, straight; secondaries apparently six or seven pairs, alternate, at a low angle, camptodrome.

The specimens upon which this form is of necessity founded are fragmentary, and complete characterization is difficult. It appears to be broadly ovate or perhaps elliptical-ovate. It may also possibly be slightly unequal-sided. The length was apparently about 9 or 10 centimeters, and the width between 4 and 4.5 centimeters.

Juglans rugosa Lesquereux was named in 1868 from material obtained from the Marshall mine, Marshall, Colo., but it was neither described nor figured at that time. The only note of explanation then given is as follows:[63] "Very nearly related to *J. acuminata* Al. Braun, a species extensively distributed in the European Miocene." This note was copied without change by Hayden[64] in 1869, and the species was alluded to in several other Hayden reports, but not until 1878[65] was it really described and figured. Now, another complication is introduced with the describing and figuring of this species. The original locality of Marshall for *Juglans rugosa* is nowhere mentioned in the "Tertiary flora," and, so far as known, none of the original specimens are extant. The diagnosis and figures in the "Tertiary flora" are based in the main on material from Evanston, Wyo., obtained "above the coal." Of the 13 figured specimens of *Juglans rugosa*, 11 are now in the collection of the United States National Museum, the missing ones being the originals of Lesquereux's Plate LIV, figure 5, and Plate LVI, figure 1. Both these specimens are said to have come from Golden, Colo., though whether from Laramie or Denver beds can not be ascertained.

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[62] U. S. Geol. Survey Bull. 204, p. 88, 1902.

In order that there may be less trouble in future in identifying these type specimens, the following list is given of their illustrations in the "Tertiary flora" and the corresponding numbers in the United States National Museum catalogue:

	Catalogue No.
Plate LIV, figure 14	454
Plate LV, figure 1	851
figure 2	455
figure 3	455a
figure 4	456
figure 5	457
figure 6	458
figure 7	460
figure 9	459
Plate LVI, figure 2	463

Of these specimens Nos. 455, 455a, 457, 458, 459, 461, and 851 are from Evanston, Wyo., and are so recorded in the Museum catalogue. No. 460 is recorded as being from Golden, Colo., but attached to the specimen is a small, obscure original label which states that it also is from Evanston, and as it agrees perfectly with the matrix of the other specimens this label is probably correct. No. 456 is said to be from Point of Rocks, Wyo., but the matrix is also like that of the Evanston specimens and unlike that ordinarily found at Point of Rocks, though we are confronted by the fact that it bears an original label recording it from the latter locality. This species was not recognized in my "Flora of the Montana formation,"[66] and it is probably safe to exclude it from Point of Rocks. It has, however, been found subsequently at many localities, such as Golden, Colo., in beds of Denver age; Carbon, Wyo., in the "Upper Laramie" of Veatch; many points in southern Colorado and northern New Mexico, in the Raton formation; the Bozeman coal field of Montana; and Black Buttes, Wyo., in beds believed by me to be of post-Laramie age.

From the above account it appears that, although named from material of Laramie age at Marshall, *Juglans rugosa* as it has come to be known is based on described and figured material from higher or post-Laramie horizons. There is no means of knowing just what the original Marshall leaves were like, beyond the fact already mentioned that they are said to resemble *Juglans acuminata*. It is for these reasons that *Juglans rugosa* is excluded from the Laramie flora. It appears to be essentially a Tertiary species, and its occurrence in Cretaceous beds must be left open to subsequent discoveries.

There is, of course, no certainty that the leaflets here described as *Juglans praerugosa* are the same as the form to which Lesquereux gave the name of *J. rugosa*, and in fact they do not differ from it very markedly. The leaves of *J. praerugosa* seem to have been thinner and do not appear particularly rugose. As a matter of fact, better material is needed before it can be completely diagnosed.

Occurrence: Laramie formation, Marshall mine, Marshall, Colo., collected by Arthur Lakes, 1890.

Hicoria angulata Knowlton, n. sp.

Plate V, figure 4.

Hicoria angulata Knowlton [nomen nudum], U. S. Geol. Survey Bull. 696, p. 319, 1919.

Fruit ovoid, truncate at base, obtusely pointed at apex, strongly several-angled (probably four) or ridged.

This beautifully preserved fruit is well shown in the figure. It is 22 millimeters long and about 14 millimeters in broadest diameter. If correctly interpreted, it should belong to that section of the living genus in which the husk or exocarp adheres closely to the shell and splits away only at maturity, and even then not to the extreme base.

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[63] Am. Jour. Sci., 2d ser., vol. 45, p. 203, 1868.

[64] U. S. Geol. Survey Terr. Third Ann. Rept. [reprint, 1873], p. 195.

[65] Lesquereux, Leo, The Tertiary flora: U. S. Geol. Survey Terr. Rept., vol. 7, p. 286, pl. 54, figs. 5, 14; pl. 55, figs. 1-9; pl. 56, figs. 1, 2, 1878.

[66] U. S. Geol. Survey Bull. 163, 1900.

In the material from Mount Carbon, near Morrison, there is another specimen of this species. It is of about the same shape as the one figured but is a little larger.

Occurrence: Laramie formation, Marshall, Colo., railroad cut between old and new stations, collected by A. C. Peale; Mount Carbon, near Morrison, Colo., collected by Arthur Lakes.

Hicoria minutula Knowlton, n. sp.

Plate V, figure 5.

Hicoria minutula Knowlton [nomen nudum], U. S. Geol. Survey Bull. 696, p. 320, 1919.

Similar to the last but very much smaller. The length is 14 millimeters and the diameter about 9 millimeters. The husk, less than 1 millimeter thick, is apparently present, and in the apical portion it may be noted becoming fibrous or slightly frayed.

It is not certain that this should be held as distinct from *H. angulata*, as it hardly differs except in size and may be only an immature specimen of that species. However, it can do no harm to consider them separately until further data can be procured.

Occurrence: Laramie formation, wooded bluff south of Marshall, Colo., collected by A. C. Peale, 1908.

Order MYRICALES.

Family MYRICACEAE.

Myrica torreyi Lesquereux.

Myrica torreyi Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1872, p. 392, 1873; idem for 1876, p. 503, 1878; Tertiary flora: U. S. Geol. Survey Terr. Rept., vol. 7, p. 129, pl. 14, figs. 3-10, 1878.
Ward, U. S. Geol. Survey Sixth Ann. Rept., p. 551, pl. 40, fig. 4, 1886; idem, Bull. 37, p. 32, pl. 14, fig. 5, 1887.
Knowlton, U. S. Geol. Survey Bull. 163, p. 34, pl. 6, figs. 1-3, 1900.
Cockerell, Colorado Univ. Studies, vol. 7, p. 150, 1910.

The type locality of this species is Black Buttes, Wyo., and all but two of the figured types are preserved in the United States National Museum (Nos. 138-142, inclusive), the others having been lost or misplaced. The species was well described and illustrated by Lesquereux, and none of the material since obtained adds materially to our knowledge of it.

Since the original finding at Black Buttes this species has been reported, on evidence of more or less value, as occurring at so many additional localities that it has largely been robbed of its value as a stratigraphic marker. Thus, Ward found it at Point of Rocks, Wyo., in beds now referred to the Mesaverde formation. These specimens are illustrated in my "Flora of the Montana formation,"[67] and although the leaves shown in figures 1 and 2 of that bulletin are probably correctly identified, that of figure 3 is more doubtful.

What was presumed to be this species was found at Dunn's ranch, 30 miles north of Laramie, Wyo., and also at Harper station, on the Union Pacific Railroad about 6 miles west of Dunn's ranch. All these localities are now referred to the Mesaverde formation. The species has also been reported from the Mesaverde formation near Meeker, Colo., and the Vermejo formation at Rockvale, near Canon City, at La Veta, near Trinidad, and at Walsenburg, Colo. It has likewise been reported from the Lance formation of Converse County, Wyo., although the specimens found there are narrower than is usual.

Occurrence: Laramie formation, Crow Creek, 25 miles southeast of Greeley, Colo. Post-Laramie (in my opinion), Black Buttes, Wyo. (types). ?Lance formation, Converse County, Wyo. Mesaverde formation, Point of Rocks, Wyo. Vermejo formation, Rockvale, La Veta, and Walsenburg, Colo.

Myrica dubia Knowlton, n. sp.

Plate V, figure 3.

Myrica dubia Knowlton [nomen nudum], U. S. Geol. Survey Bull. 696, p. 394, 1919.

Leaves small, lanceolate, obtusely wedge-shaped at base (apex destroyed); margin entire; midrib relatively thick; intramarginal vein well marked, other nervation consisting of thin, irregular veins connecting the midrib and intramarginal vein.

This species is most closely related to *Myrica torreyi* Lesquereux[68] but differs in its smaller size, more obtuse base, and above all the perfectly entire margin.

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[67] U. S. Geol. Survey Bull. 163, p. 34, pl. 6, figs. 1-3, 1900.

[68] Lesquereux, Leo, U. S. Geol. Survey Terr. Rept., vol. 7, pl. 16, figs. 3-10, 1878.

Occurrence: Laramie formation, Popes Bluff, just west of Pikeview, Colo. (sec. 14, T. 13 S., R. 67 W.), collected by A. C. Peale and M. I. Goldman, 1908.

Myrica oblongifolia Knowlton, n. sp.

Plate XXI, figure 1.

Myrica oblongifolia Knowlton [nomen nudum], U. S. Geol. Survey Bull. 696, p. 396, 1919.

Leaves membranaceous, long-elliptical, rounded to a slightly wedge-shaped base and to an obtuse apex; margin with numerous small, sharp teeth for the lower two-thirds, thence undulate and nearly entire to the apex; nervation paryphodrome, with a slender marginal nerve around the leaf 1 millimeter from the border; slender nerves from the outside of this intramarginal nerve appear to enter the teeth; nerves very numerous, yet at an acute angle, irregular and broken, often joining, ending when they reach the border, in the intramarginal vein; nervilles usually percurrent.

This species is based upon the single fine specimen figured. It is about 8.5 centimeters long and 4 centimeters broad, with a petiole 0.5 centimeter long. It is a broad, long-elliptical leaf which is about equally rounded to both base and apex. The teeth begin within 1 centimeter of the base, and are fine, sharp-pointed, and directed toward the apex. In the upper portion of the blade the teeth are reduced to mere undulations, and at the apex the margin is nearly entire.

The most pronounced characteristic of this leaf is the strongly marked paryphodrome nervation—that is, a thin intramarginal nerve extending all around the leaf about 1 millimeter distant from the margin. The other nerves, or secondaries, if they may be so called, are very numerous, at a low angle of divergence, and much broken and irregularly joined.

It is difficult to determine the genus to which this leaf should be referred. There are a number of living genera that have this peculiar paryphodrome nervation, as, for example, *Tristania* of the family Myrtaceae, *Ardisia* of the Myrsinaceae, and *Dodonaea* of the Sapindaceae, as well as many others less likely to be represented in a fossil state. On the whole it appears best to refer it to *Myrica* because it agrees in this character with many living species of the genus—for example, *M. terebiuttacea* Göppert, from tropical America, and *Myrica* sp. from Brazil—and also because it is evidently allied to *Myrica torreyi* Lesquereux, a fossil species of wide vertical range which is also found in the Laramie. *Myrica torreyi* is undoubtedly the nearest relative of *M. oblongifolia* that has not been described from material collected in this area. It differs, however, in being narrowly lanceolate instead of broadly oblong and in being linear-acuminate instead of obtuse. The teeth in *M. torreyi* are larger and more distant.

This new species does not appear to be closely related to any of the other fossil American species of *Myrica*. It has much the shape and marginal dentation of *Celastrophyllum decurrens* Lesquereux, from the Dakota sandstone, but that species differs absolutely in the nervation. *Myrica oblongifolia* is also in outline and serration like the figures of *Quercus haidingeri* Ettingshausen given by Lesquereux,[69] but that species also differs in nervation.

Occurrence: Laramie formation, Marshall mine, Marshall, Boulder County, Colo.

Order SALICALES.

Family SALICACEAE.

Salix myricoides Knowlton, n. sp.

Plate IV, figure 7.

Salix myricoides Knowlton [nomen nudum], U. S. Geol. Survey Bull. 696, p. 569, 1919.

Leaf linear-lanceolate, with a very long, slenderly acuminate apex and an apparently rather obtusely wedge-shaped base; margin entire; midrib relatively very thick; secondaries very numerous, probably about 20 pairs, approximately at right angles to the midrib, each joining the one next above by a broad loop just inside the margin; finer nervation obsolete.

The only example of this characteristic species observed is the one here figured. It is about 8 centimeters in length and 1 centimeter in maximum width; this width holds for more than half the length of the leaf. The leaf appears to have been rather thick, and as it is the upper side that is exposed, the nervation is obscured, all that can be made out being the very thick midrib and the numerous close, parallel secondaries nearly at right angles to it.

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[69] Lesquereux, Leo, U. S. Geol. Survey Terr. Rept., vol. 7, p. 156, pl. 20, figs. 9, 10, 1878.

Occurrence: Laramie formation, cut on Moffat railroad (Denver & Salt Lake) about 6 or 8 miles north of Golden, Colo., collected by A. C. Peale, 1908.

Salix wyomingensis Knowlton and Cockerell.

Plate IV, figures 3, 4, 8.

Salix wyomingensis Knowlton and Cockerell, U. S. Geol. Survey Bull. 696, p. 572, 1919.

Salix integra Göppert, Deutsch. geol. Gesell. Zeitschr., vol. 4, p. 493, 1852.

. Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1873, p. 397, 1874; Tertiary flora: U. S. Geol. Survey Terr. Rept., vol. 7, p. 167, pl. 7, figs. 1, 2, 1878.

The American specimens on which is based the determination that this form occurs in the United States are included in the collections of the United States National Museum (No. 197) and are preserved on the red baked shale characteristic of a certain horizon at Black Buttes, Wyo. They agree fairly well with the European figures of this species, and the species may be considered as probably present in this country.

In the "Tertiary flora" Lesquereux mentions a single example from Golden, Colo. This specimen is No. 837 of the United States National Museum collection and is preserved on a hard fine-grained whitish sandstone characteristic of the Laramie at Golden. This species is also represented by specimens from Coal Creek, Boulder County, Colo., one of the best preserved of which is shown in Plate IV, figure 8.

In a collection made at Marshall by Peale there are a number of willow leaves, the most perfect of which are here figured (Pl. IV, figs. 3, 4). They are evidently fairly thick, but the nervation is obscure. So far as can be made out, however, they are the same as the form figured by Lesquereux under the name *Salix integra*. It is to be noted that the leaves of *Salix* are often lacking in diagnostic characters, and they are described with difficulty.

Occurrence: Laramie formation, Golden, Colo., original collections studied by Lesquereux; Coal Creek, Boulder County, Colo., collected by N. L. Britton about 1884; Marshall, Colo., collected by A. C. Peale, 1908. Post-Laramie (in my opinion), Black Buttes, Wyo.

Salix brittoniana Knowlton, n. sp.

Plate XXI, figure 8.

Salix brittoniana Knowlton [nomen nudum], U. S. Geol. Survey Bull. 696, p. 565, 1919.

Leaf of firm texture, narrowly lanceolate, tapering below to a long, narrowly wedge-shaped base; apex not preserved; margin perfectly entire; nervation strong, pinnate, consisting of a relatively strong midrib and probably 8 or 10 pairs of alternate, remote secondaries, each of which arises at an acute angle, passes upward for a long distance, and disappears near the margin or unites by a slender apex to the secondary next above; nervilles none; finer nervation obscure but apparently consisting of a minute quadrangular areolation.

The type of this species, and unfortunately the only one observed, lacks the upper portion of the leaf and would not be described as new except for the marked difference between it and anything else thus far noted in these beds. The portion observed, which includes the base, is 5.5 centimeters long and was possibly twice this length when perfect; the width does not exceed 1 centimeter. Its principal feature is the secondary nervation, described above.

As regards size, shape, and margin this leaf is very much like many leaves that have been referred to *Salix angusta* Al. Braun,[70] but it differs distinctly in the nervation; so also it agrees with *S. amygdalaefolia* Lesquereux as regards the type of secondary nervation but differs in shape and margin. It is believed to be hardly worth while to follow resemblances further, as willow leaves are in general so variable, yet it is thought that this species, fragmentary as the type is, is sufficiently well marked to be readily recognized in the future. It has been named in honor of N. L. Britton, director of the New York Botanical Garden, who collected it.

Occurrence: Laramie formation, Coal Creek, Boulder County, Colo. (Laramie), collected by N. L. Britton about 1880.

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[70] Cf. Lesquereux, Leo, The Tertiary flora: U. S. Geol. Survey Terr. Rept., vol. 7, pl. 22, fig. 4, 1878.

Populus? distorta Knowlton, n. sp.

Plate IV, figure 6.

Populus? distorta Knowlton [nomen nudum], U. S. Geol. Survey Bull. 696, p. 488, 1919.

Leaf of small size, unequal sided, probably more or less distorted or malformed, outline now broadly ovate, possibly nearly circular when perfect, base abruptly rounded and truncate, apex obtusely acuminate; three-ribbed from the extreme base of the blade, midrib with about two pairs of thin secondary branches high up above the middle, lateral much arched outward, each with several thin branches on the outside.

This form is represented by the single example figured, and this seems not to be normal in that it was probably nearly circular in outline when perfect, though now it is distinctly narrowed on one side. The length is 4.5 centimeters and the width about 3 centimeters, though if the supposition of its abnormality is correct it should have been a little over 4 centimeters in width.

This appears to be a poplar of the type of *Populus arctica* Heer [71]—that is, on the supposition that one side has become reduced, probably by injury or pressure—but as it may be normal the reference to *Populus* has been questioned.

Occurrence: Laramie formation, Cowan station, 10 miles south of Denver, Colo., collected by F. H. Knowlton.

Order FAGALES.

Family FAGACEAE.

Quercus praeangustiloba Knowlton,

Plate V, figures 6, 7 (types).

Quercus praeangustiloba Knowlton, U. S. Geol. Survey Bull. 696, p. 535, 1919.

Quercus angustiloba Al. Braun. Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1872, p. 378, 1873; idem for 1873, p. 381, 1874; idem for 1876, p. 506, 1878; Tertiary flora: U. S. Geol. Survey Terr. Rept., vol. 7, p. 161, pl. 21, figs. 4, 5, 1878. [Lesquereux's original figures of these types are here reproduced.]

The two specimens upon which this species is based, and apparently the only ones ever obtained, are in the collections of the United States National Museum (Nos. 191, 192). They are preserved on the white fine-grained sandstone characteristic of the Laramie at Golden, Colo., and are rather obscure, though the figures given by Lesquereux and here reproduced show them very well.

These leaves have until now been referred to the European *Quercus angustiloba* Al. Braun,[72] but as that species occurs in the Oligocene it seems inherently improbable that it should be common also to the American Upper Cretaceous, though of course this is not in itself proof that they are not the same. In the matter of outline they are certainly very similar, but the nervation is obscurely retained in the European specimens, and until material is obtained showing them to be identical it seems best to treat them as distinct.

These American leaves have a rather strong resemblance to certain leaves of *Artocarpus*. In both the leaves under consideration, the strong secondaries next above the ones going to the lower lobes pass directly toward the sinuses, but it is impossible to see whether they enter the margin or pass around the sinus as intramarginal veins. In one of the larger lobes there seems to be an intramarginal vein, as in *Artocarpus*, but it is too indistinct to be made the basis for transferring them to that genus.

The specimen from Campbell's quarry, Cross Lakes, La., referred by Lesquereux [73] to *Quercus angustiloba*, is also in the United States National Museum (No. 2551). It proves to be a minute fragment without base, apex, or perfect sides and is absolutely worthless in determining the presence of this or any other species.

Occurrence: Laramie formation, Golden, Colo.

Quercus straminea Lesquereux.

Quercus straminea Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1872, p. 373, 1873; Tertiary flora: U. S. Geol. Survey Terr. Rept., vol. 7, p. 151, pl. 19, figs 6, 7, 1878.

The type specimens of this species are preserved in the United States National Museum (fig. 6 = No. 173, fig. 7 = No. 174) and are on the hard sandstone matrix of the Laramie. These two specimens are so unlike that it was at one time thought best to separate them; in fact, Lesquereux himself has called attention to this difference. On this point he says:

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[71] Lesquereux, Leo, The Tertiary flora: U. S. Geol. Survey Terr. Rept., vol. 7, pl. 23, figs. 1-5, 1878.

[72] Braun, Al., in Ludwig, Rudolph, Paleontographica, vol. 8, p. 103, pl. 36, fig. 3, 1860.

[73] U. S. Nat. Mus. Proc., vol. 11, p. 25, 1888.

These leaves seem to represent two different species. They have, however, a common character—that of the yellowish, shining secondary veins, which I have not seen on any other species of fossil plant of this locality. The leaf in figure 6 is smaller, with the secondary veins at a more acute angle of divergence; it has, however, the same character of nervation, shorter intermediate tertiary veins, and more or less distinct veinlets, oblique to the secondary veins. In both leaves, also, the basilar veins are marginal and ascend to the branches of the secondary nerves above.

In a subsequent paper describing plants from the Denver formation Lesquereux [74] identified this species with question, saying:

The leaf which I refer to this species is oval, apparently denticulate near the apex, and narrower than those figured in Plate XIX, figures 6, 7. It may, therefore, belong to a different species.

I have not seen these forms, but to judge from the remarks quoted it would seem that they are properly excluded from *Q. straminea.*

Occurrence: Laramie formation, Golden, Colo.

Quercus eximia Knowlton, n. sp.

Plate XXI, figure 2.

Quercus eximia Knowlton [nomen nudum], U. S. Geol. Survey Bull. 696, p. 527, 1919.

Leaf oblong-lanceolate, gradually or evenly narrowed from what appears to be about the middle of the blade to a long acuminate apex; margin provided with few distant upward-pointing teeth; midrib very strong, running directly to the apex; secondaries alternate, 10 or more pairs in the upper half of the leaf, emerging at an angle of approximately 30°-40°, some apparently entering the teeth but most of them arching to join the one next above, thence forming a practically continuous line just inside the margin; finer nervation entirely obsolete.

This species, which unfortunately is represented only by the fragmentary example figured, must have been 18 or 20 centimeters long, for the portion preserved, which appears to be only about half of the leaf, is 11 centimeters long. It is about 4 centimeters in greatest width and tapers gradually to an acuminate apex. One side of the leaf is provided with several rather prominent upward-pointing teeth; the other side is merely undulate with but faint indications of teeth. The secondaries are distinctly alternate, each usually—so far as can be made out—arching just inside the border to join the one next above by a sort of bifurcation in the upper portion, thus producing a nearly continuous intramarginal line, a character observed in certain living leaves of this genus.

Among described forms this has a decided resemblance to *Quercus lyelli* Heer,[75] from the Atanekerdluk beds of Greenland. It is, for example, very close to the forms shown in Heer's figures 7b of Plate LXX, 9 and 10 of Plate LXXII, and 1, 2, and 4 of Plate LXXIII, differing in the thicker midrib and stronger secondaries, which are more continuous and, so far as can be made out, less branched. The teeth in the two forms are very similar. There can be almost no question as to their generic identity, and but for a number of quite differently appearing forms included by Heer in his species there would be little question of their specific similarity. Without more and better material I have thought it best to keep them apart.

Occurrence: Laramie formation, Coal Creek, Boulder County, Colo.

Quercus viburnifolia? Lesquereux.

Quercus viburnifolia Lesquereux, Tertiary flora: U. S. Geol. Survey Terr. Rept., vol. 7, p. 159, pl. 20, figs. 11, 12, 1878; U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1876, p. 505, 1878; Harvard Coll. Mus. Comp. Zoology Bull., vol. 16, p. 46, 1888.
Ettingshausen, Roy. Soc. London Proc., vol. 30, p. 232, 1880.

Quercus triangularis Göppert [in part]. Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1872, p. 377, 1873.

Quercus attenuata? Göppert. Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1873, p. 389, 1874.

One of the figured types of this species (the original of fig. 11 in the "Tertiary flora") is preserved in the United States National Museum (No. 186), together with the others that were the basis for Lesquereux's remarks concerning this form. None of them are very perfect, yet a careful study brings out well the characters upon which the species is founded. This original specimen is from Sand Creek, Colo., and others were reported from Golden, Colo., and Black Buttes, Wyo., the latter preserved on red baked shale. The matrix of the

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[74] Lesquereux, Leo, Fossil plants collected at Golden, Colo.: Harvard Coll. Mus. Comp. Zoology Bull., vol. 16, p. 46, 1888.

[75] Flora fossilis arctica, vol. 7, pt. 1, p. 87, pl. 66, figs. 4, 5a; pl. 70, fig. 7b; pl. 72, figs. 1-10; pl. 73, figs. 1-6, 1883.

Golden specimen shows it to have come from the andesitic beds, probably on South Table Mountain, and no less than 11 additional examples were found by Lesquereux in the collection from these beds determined for the Museum of Comparative Zoology. This species has also been reported by Ettingshausen in the flora from Alum Bay, England.

A number of well-preserved leaves apparently belonging to this species have been found in the material from Converse County, Wyo. They do not differ essentially from the type specimen shown in Lesquereux's figure 11.

The basal portion of what appears to be a small leaf of this species has been found in material from Mount Bross, Middle Park, Colo., and a rather narrow but otherwise nearly normal leaf is contained in the small collection made in the Laramie at Crow Creek, Colo.

Occurrence: Laramie formation, Canfield ranch on Crow Creek, about 25 miles northeast of Greeley, Colo., collected by F. H. Knowlton and T. W. Stanton, June, 1896. Post-Laramie (in my opinion), Black Buttes, Wyo. Denver formation, Sand Creek, 18 miles east of Denver, Colo. (type); Golden, Colo. Lance formation, gulch south of Lightning Creek, opposite mouth of Box Elder Creek, Converse County, Wyo., collected by T. W. Stanton, July, 1896.

Order URTICALES.

Family MORACEAE.

Artocarpus lessigiana (Lesquereux) Knowlton.

Plate XII, figure 1; Plate XXII, figure 4.

Artocarpus lessigiana (Lesquereux) Knowlton, Science, vol. 21, p. 24, 1893; U. S. Geol. Survey Bull. 152, p. 42, 1898.

Myrica? lessigiana Lesquereux, U. S. Geol. and Geog. Survey Terr. Bull., vol. 1, p. 386, 1876; idem, Ann. Rept. for 1874, p. 312, 1876.

Myrica? lessigii Lesquereux, Tertiary flora: U. S. Geol. Survey Terr. Rept., vol. 7, p. 138, pl. 64, fig. 1, 1878; U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1876, p. 503, 1878.

Leaf very large, coriaceous, oblong, deeply pinnately lobed, the lobes opposite, oblong-lanceolate, pointed, at an open angle of divergence, separated usually to a point near the midrib, where they are joined by broad, rounded sinuses; midrib very thick; secondaries of two orders, the first strong, ascending to the points of the lobes and branched on either side, the second smaller, emerging from the midrib between the others, passing up to the sinus, where they divide into two branches that arch around the sinus just inside the margin and then follow the lobes in festoons, anastomosing with the tertiaries; tertiaries numerous, alternate, curved more or less in passing to the margin, along which they form long festoons just inside the border; ultimate areolation in the main quadrangular, formed by divisions at right angles to the tertiaries.

These magnificent leaves were from 20 to 30 centimeters or more long and from 12 or 15 to 18 centimeters wide. They are thick, probably coriaceous, and broadly oblong, and the lobes are connected by broad, rounded sinuses.

This species was first described by Lesquereux under the name *Myrica? lessigiana* from material collected on Coal Creek, Boulder County, Colo., where it was found just above the coal. It was obtained, according to Lesquereux, by Gen. W. H. Lessig, for whom it was named. For many years the location of the type specimen was unknown, but recently it came to light among the collections donated to the United States National Museum by R. D. Lacoe, of Pittston, Pa., and is now No. 7172 of the Museum collection. It was with great doubt that this specimen was referred to *Myrica* by Lesquereux,[76] who says:

> It is doubtful if this leaf represents * * * a species of the section of the *Comptonia*. It resembles *Comptonia grandifolia* Unger, which till now has been considered as the giant representative of this section but whose leaf is scarcely half as large as this.

The reference of these leaves to the genus *Artocarpus* was first suggested by Nathorst[77] in his paper describing a new species of the genus from the Cenomanian of Greenland. After discussing a number of poorly defined fossil species and describing the new form (*A. dicksoni*), which he was fortunate enough to find associated with undoubted fruits, he calls attention to its resemblance to and possible identity with the *Aralia pungens* and *Myrica? lessigii* of Lesquereux. A comparison of these leaves with leaves of living species of *Artocarpus*, particularly of the common breadfruit (*A. incisa*), proves beyond reasonable doubt that Nathorst's supposition is correct, and they are consequently referred to this genus. In leaves of *Artocarpus incisa* before me the base is broadly wedge-shaped, and the distance to which the lobation extends decreases toward the apex, or just the reverse of what occurs in *A. lessigiana*. The nervation in the lobes is exactly the same as in the living leaf, including the arching of the tertiaries, the intramarginal nerve, and the secondary emerging from the midrib, dividing and passing around on either side of the sinus. The Greenland species (*A. dicksoni*) seems to approach more closely in outline to the living *A. incisa* than the leaves under consideration. No fruits or flowers have been found in the American deposits that can be referred to this genus.

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[76] Lesquereux, Leo, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1874, p. 312, 1876.

[77] Nathorst, A. G., Ueber die Reste eines Brotfruchtbaums: K. svenska Vet.-Akad. Handl., vol. 24, p. 7, 1890.

After the discovery of a well-authenticated species of *Artocarpus* in the Cenomanian of Greenland it was logical to expect to find representatives in later formations on the American continent, and such has been shown to be the case. The genus is now confined in its native state to tropical Asia and the Malay Archipelago, though once extending as far north as latitude 70° in Greenland. In America it has been found in the Laramie and Denver formations of the Denver Basin, in the Vermejo and Raton formations of southern Colorado and northern New Mexico, in the Wilcox group of the Gulf region, and in the Miocene (auriferous gravels) of California.

The form most closely related to *Artocarpus lessigiana* is undoubtedly *A. dissecta* Knowlton,[78] from the Vermejo formation at Walsenburg, Colo. This form is a leaf of large size, deeply cut into at least three pairs of opposite lobes, the lower pair remote from the ones next above and connected with them by an exceedingly narrow wing that is hardly more than the petiole. The lower pair of lobes are also curiously cut into almost to the midrib on the lower side, but the upper side is attached by the whole base. Otherwise the general outline, number, and shape of the lobes, as well as the type of nervation of the lobes, are practically the same in both, and, as I have pointed out in my paper on the flora of the Raton Mesa region, it is entirely possible that a series of leaves would show them to be identical. As the facts now stand, however, it seems best to consider them as distinct.

Occurrence: Laramie formation, Coal Creek, Boulder County, Colo. (type), collected by W. H. Lessig, now in United States National Museum; Marshall, Colo., half a mile south of railway station, in first draw north of white sandstone bluff, just above the highest coal of the vicinity, collected by F. H. Knowlton and G. C. Martin, 1908; Cowan station, 10 miles south of Denver, Colo., collected by F. H. Knowlton.

Artocarpus liriodendroides Knowlton, n. sp.

Plate XXI, figure 3.

Artocarpus liriodendroides Knowlton [nomen nudum], U. S. Geol. Survey Bull. 696, p. 100, 1919.

Leaf of medium size and probably membranaceous in texture, deeply cut into at least three pairs of large, opposite, distant lobes, which are, with the exception of the lowest, attached by the whole, evenly expanded base, which continues along the petiole between the lobes as a narrow web or wing and also persists below the lowest pair of lobes nearly or quite to the base of the petiole; lowest segment ovate, rather obtuse, attached by about one-third of its width; primary midrib strong, straight, margined between and below the lobes by the narrow wing; nervation of lowest segment consisting of a plainly marked secondary that forms a "midrib" very near the center and four or five pairs of thin, alternate branches that form broad loops just inside the margin; nervilles anastomosing in all directions.

This interesting specimen is, so far as known, the only one found in these beds. Unfortunately it is so fragmentary that its complete size and appearance can not be determined. The portion retained is about 10 centimeters long, of which some 4 centimeters is taken up with the petiole below the lower pair of lobes; but, to judge from the undiminished thickness of the midrib above, it must have been considerably larger. The lower, nearly perfect lobe, which is attached by a narrowed base only 5 millimeters wide, is 3.5 centimeters long and 1.5 centimeters broad in the middle. The segment next above is 2.5 centimeters broad at the base and is preserved for a length of only 3 centimeters. None of the other lobes is as well preserved, though all appear to be opposite. The nervation, marginal wing to the petiole, and other features are well shown in the figure.

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[78] Knowlton, F. H., U. S. Geol. Survey Prof. Paper 101, p. 267, pl. 42, fig. 6, 1918.

This species is undoubtedly most closely related to *Artocarpus dissecta* Knowlton,[79] from the Vermejo formation near Walsenburg, Colo., with which it agrees in general type, though differing in a number of important particulars. In the first place, although, of course, this difference is not of cardinal importance, it may be mentioned that *Artocarpus dissecta* is nearly twice the size of the present species. In *A. dissecta* the lower lobes are attached by the whole width of the segment, and the main secondary or "midrib" is very close to the lower margin, which gives the segment the appearance of being cut away on the lower side. In *A. liriodendroides*, on the other hand, the lower segment is attached by a much contracted base, and the "midrib" is practically central. In shape and major nervation the upper segments appear to be much the same in both forms. The petiolar wing connecting the segments is much more pronounced in *A. liriodendroides* and extends down the petiole below the lower segment for a greater distance than in *A. dissecta*. It is quite possible that if a series of specimens from both localities were available the two forms might be shown to approach more closely or even to combine, but with only a single example from each locality, the forms seem sufficiently distinct to warrant different names.

The leaf here described has an undoubted resemblance to what has been called *Liriodendron* from the Dakota sandstone of Kansas, being in a way intermediate between *L. pinnatifidum* Lesquereux[80] and *L. snowii* Lesquereux.[81] The former is described by its author as "pinnately, alternately lobed; lobes short, obtuse truncate or angular, abruptly narrowed into an obtusely lobate or subtruncate apex, separated by broad, unequal sinuses," and the latter is described as "pinnately, horizontally divided into linear, obtuse lobes, distant and distinct for their whole length, attached by their whole base to the thick median nerve (petiole) like pinnules of a compound leaf." The specimens upon which *L. pinnatifidum* is based are imperfect, so that it is not possible to make out the whole leaf with satisfaction, but it appears to have had at least three pairs of large, obtuse, irregularly quadrangular, alternate lobes, which are separated by broad, rounded sinuses. The portion of the blade between the lobes is sufficiently broad to support a considerable nervation, whereas in the Laramie species the interlobular margin or wing is too narrow to be provided with nervation. Superficially the leaf of *Artocarpus liriodendroides* appears to be most like *L. snowii*, for unless examination is careful enough to disclose the narrow wing between the lobes it seems essentially identical with that species.

Occurrence: Laramie formation, Coal Creek, Boulder County, Colo., collected by N. L. Britton about 1884.

Ficus? smithsoniana? (Lesquereux) Lesquereux.

Plate XXI, figure 4.

Ficus smithsoniana (Lesquereux) Lesquereux, Tertiary flora: U. S. Geol. Survey Terr. Rept., vol. 7, p. 200, pl. 32, fig. 5, 1878.

Knowlton, U. S. Geol. Survey Prof. Paper 101, p. 305, 1918.

Juglans smithsoniana Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1872, Supplement, p. 16, 1873.

The type of this species is preserved in the collections of the United States National Museum (No. 106a) and is said to have come from "Fishers Peak, Raton Mountains, N. Mex." It is preserved on the same piece of matrix as the type of *Geonomites ungeri* Lesquereux, and there is thus every reason to suppose that the locality is correctly stated. However, no additional specimens of this species were found in the very extensive collections from the Raton Mesa region recently studied.

In the collections from Mount Carbon, Morrison, Colo., there is a single example that may be this species. The matrix on which it is preserved is the coarse-grained sandstone so characteristic of many of the Laramie deposits and hence is not well fitted to retain the details of nervation. The primary nervation is similar to that of the type, but the shape of the blade differs somewhat in being a little broader and more tapering both at base and apex. At least this identification must be considered as open to some question.

Occurrence: Raton formation (type), Fishers Peak, Raton Mountains, Colo. Laramie formation, Mount Carbon, Morrison, Colo., collected by Arthur Lakes, 1890.

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[79] Knowlton, F. H., U. S. Geol. Survey Prof. Paper 101, p. 287, pl. 42, fig. 4, [illegible]

[80] Lesquereux, Leo, The flora of the Dakota group: U. S. Geol. Survey Mon. [illegible], p. 71, figs. 4, 5, 1892.

[81] Idem, p. 70, figs. 1, 2.

Ficus pealei Knowlton, n. sp.

Plate XI, figure 6.

Ficus pealei Knowlton [nomen nudum], U. S. Geol. Survey Bull. 696, p. 284, 1919.

Leaf ovate, apparently abruptly rounded below to the truncate base, and more gradually rounded above to the obtusely acuminate apex; margin perfectly entire; nervation pinnate, midrib comparatively thick; secondaries four pairs, alternate, thin, remote, at an angle of approximately 40°, slightly curved upward, apparently camptodrome.

The example figured is the most nearly complete of those observed. It is about 8.5 centimeters in length and 4.5 centimeters in width. It is not a very marked leaf, its strongest characters being the regular ovate shape, very thick midrib, and few, thin, alternate secondaries. The finer nervation is not retained.

In shape this leaf resembles certain of the leaves referred to *Ficus arenacea* Lesquereux,[82] and the nervation is more of the type of *Ficus pseudo-populus* Lesquereux,[83] but it differs essentially from either.

Occurrence: Laramie formation, Cowan station, 10 miles south of Denver, Colo., collected by A. C. Peale, for whom it is named.

Ficus planicostata Lesquereux.

Ficus planicostata Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1872, p. 393, 1873; idem for 1874, p. 304, 1875; idem for 1876, pp. 181, 508, 1878; U. S. Geol. and Geog. Survey Terr. Bull., vol. 1, p. 379, 1876; Tertiary flora: U. S. Geol. Survey Terr. Rept., vol. 7, p. 201, pl. 31, figs. 1-8, 10-12, 1878.

Ettingshausen, Roy. Soc. London Proc., vol. 30, p. 232, 1880.

Hollick, Louisiana Geol. Survey Ann. Rept. for 1899, pt. 5, pp. 276, 282, 1890.

Newberry, The later extinct floras of North America: U. S. Geol. Survey Mon. 35, pp. 88, 146, pl. 46, fig. 1, 1898.

Knowlton, U. S. Geol. Survey Bull. 163, p. 52, pl. 10, fig. 4, pl. 12, figs. 2-4, 1900; U. S. Geol. Survey Bull. 204, p. 56, 1902.

Leaves of medium size, subcoriaceous, entire, elliptical or broadly oval, slightly acuminate or obtuse, rounded to a short thick petiole, palmately three-nerved from the top of the petiole, rarely from a short distance above the base; primary and secondary nerves broad, flat, all camptodrome, as well as their divisions.—Lesquereux.

This species appears to have been first described from specimens collected at Black Buttes, Wyo., and subsequent events prove that this is the principal locality for it. All the types figured in the "Tertiary flora" are from this place, and these, together with numerous duplicates, are preserved in the United States National Museum (Nos. 271-280). There is also a single example in the Museum (No. 895) said to have come from Coal Creek, Boulder County, Colo., a statement made probable by the finding of at least two fairly perfect examples in the material from this locality, one belonging to Columbia University (Nos. 119, 120) and now deposited in the New York Botanical Garden and the other belonging to the United States National Museum (No. 3611). This species is a very fine and characteristic one and was well described and figured by Lesquereux. It does not appear to have been obtained by Ward, who collected extensively at Black Buttes in 1881, but it has been reported from other localities with more or less certainty by various writers. It is, for instance, reported by Ettingshausen[84] from the Eocene of Alum Bay, England, which appears to be its only Old World occurrence. Hollick[85] reports it from the Wilcox of Louisiana, but, as he says, the specimen so referred is very much larger than even the largest specimens of *F. planicostata* figured by Lesquereux. The strong lateral secondaries arise at some distance above the apex of the petiole, whereas in the typical *F. planicostata* they usually take their origin at the very base of the blade. The general appearance of the leaf, however, aside from the particulars mentioned above, is very like that of *F. planicostata*, and Hollick's reference may perhaps be permitted to stand. In my "Flora of the Montana formation,"[86] I referred to this species with some question a single leaf from Coalville, Utah, and a number from Dunn's ranch, on the Laramie Plains, Wyo. Newberry[87] mentions and figures a single leaf from the upper part of the Clarno formation at Bridge Creek, Oreg. The leaves from the Montana group may be correctly determined, though there are differences, but the leaf from Bridge Creek should probably be referred to another species.

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[82] Lesquereux, Leo, The Tertiary flora: U. S. Geol. Survey Terr. Rept., vol. 7, pl. 29, fig. 1, 1878.

[83] Idem, pl. 34, figs. 1, 12.

[84] Roy. Soc. London Proc., vol. 30, p. 232, 1888.

[85] Hollick, Arthur, Louisiana Geol. Survey Ann. Rept. for 1899, pt. 5, p. 282, pl. 36, 1900.

[86] U. S. Geol. Survey Bull. 163, p. 52, pl. 10, fig. 4; pl. 12, figs. 2-4, 1900.

[87] U. S. Geol. Survey Mon. 35, p. 88, pl. 46, fig. 1, 1898.

A single broken leaf from Green Mountain, Golden, Colo., I am unable to distinguish from this species, but as it is only the basal portion I may be in error.

In the material from the vicinity of the Douglas mine, Sedalia, Colo., I find a single small leaf that is referred with some hesitation to this species. It is smaller than the ordinary leaves of *F. planicostata*, being only about 4 centimeters in length and 3 centimeters in width, and is obtusely wedge-shaped instead of rounded or subcordate at the base, and, further, the lateral ribs, which arise at the very base of the blade, have a greater number of secondary branches than is usual in this species. However, the thick texture of the leaf, the palmately three-ribbed nervation, and the strong nervilles are all suggestive of *F. planicostata*. If numerous other leaves agreeing with this one are found, it should be removed, either as a new variety or possibly as a full species.

The recently collected material from the Denver beds also contains at least one example that apparently must be referred to *F. planicostata*. It is about the size of the largest example figured by Lesquereux [88] and has the short petiole preserved. It is slightly less rounded at the base than is usual with this species, but otherwise I am unable to see any mark of difference.

The material from Rock Springs also embraces a single fairly well preserved leaf that, although not quite normal, must be referred to this species. It is a rather small leaf with a long petiole and is slightly less full and rounded at the base than is usual in *F. planicostata*, but in shape (other than as just noted), as well as in the primary and secondary nervation, it is indistinguishable.

Occurrence: Laramie formation, Coal Creek, Boulder County, Colo.; Hoyt coal mine, 1 mile south of Golden, Colo. Post-Laramie (in my opinion), Black Buttes, Wyo. (types). Denver formation, Golden and Sedalia, Colo. Wilcox formation, Shreveport, La. Mesaverde formation, Rock Springs, Wyo.

Ficus cockerelli Knowlton.

Plate XII, figure 2; Plate XXIII, figures 1, 2.

Ficus cockerelli Knowlton, U. S. Geol Survey Bull. 696, p. 273, 1919.

Ficus latifolia (Lesquereux) Knowlton, U. S. Geol. Survey Bull. 152, p. 102, 1898. [Homonym, Kunth, 1846.]

Ficus planicostata latifolia Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1872, p. 393, 1873; Tertiary flora: U. S. Geol. Survey Terr. Rept., vol. 7, p. 202, pl. 31, fig. 9, 1878. [Lesquereux's original figure is here reproduced as Pl. XII, fig. 2.]

Leaves thick, very large, 9 to 15 centimeters long, 10 to 14 centimeters broad, from nearly circular to short oblong, a little longer than broad, heart-shaped at base, evenly rounded at apex; margin perfectly entire; petiole short, thick; leaf strongly palmately three-ribbed from the apex to the petiole; the two lateral ribs form an angle of about 40° with the central or midrib and thence proceed nearly straight to the margin high above the middle, sending off from their outer side from 8 to 10 well-developed, often somewhat irregular secondaries, the lowest of which supports 6 to 8 tertiaries; midrib naked for some distance above the insertion of the lateral primaries, then giving rise to three or four strong, alternate, distant nerves on each side, which branch in the same manner as the lateral nerves; secondary and tertiary nerves arching near the margin by rounded loops; nervilles very prominent, usually simple, and curved or several times subdivided so as to form small quadrangular meshes.

When this form was first described by Lesquereux he was in doubt as to whether it should be ranked as a large, broad-leaved variety of *F. planicostata* or regarded as specifically distinct. In the "Tertiary flora," page 202, he reiterates this expression of doubt, but as he had found only two leaves of this character, he was inclined to regard it as only a variety of *F. planicostata*. He remarks, however, that among very numerous examples of *F. planicostata* there appeared to be no marked variation from the normal size and shape, whereas the species under consideration is twice as large and has a heart-shaped base. The nervation is of precisely the same character in both.

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[88] Op. cit. (Tertiary flora), pl. 31, fig. 1.

The fortunate discovery of a number of well preserved leaves of this species in the coarse sandstones at Hoyt's coal mine, near Golden, Colo., and also at Marshall's coal mine, in Boulder County, Colo., makes it possible to arrive at a better understanding of this form, which it now seems best to raise to full specific rank. It turns out that the smallest leaf that has been found is the original type from Black Buttes,[89] while the largest is fully 15 centimeters long and 14 centimeters broad. They are undoubtedly very closely allied to *F. planicostata* but differ from it in being uniformly at least twice the size and without intermediate forms and in being heart-shaped at the base. This species is also closely allied to *F. speciosissima* Ward,[90] from Point of Rocks, Wyo., which differs merely in being more markedly heart-shaped at the base and in having the nervilles joining the arches of the secondary and tertiary nervation to the margin, either character being of special importance. *Ficus speciosissima* is also slightly inequilateral, thus approaching certain forms of *F. tiliaefolia*.

The figured type of *F. latifolia* (U. S. Nat. Mus. No. 278) is from Black Buttes, Wyo. The other type specimen is said to have come from Golden, Colo., but as it can not be found in the Museum collections I can not state whether it came from the true Laramie or the Denver formation, but inasmuch as all the recent collections from Golden containing it are in the true Laramie, it is probably a lower or true Laramie species.

As the specific name *latifolia* proved to be a homonym of a living species (Kunth, 1846), it has been necessary to give this form a new name. It is named in honor of Prof. T. D. A. Cockerell, of Boulder, Colo., a well-known student of the Colorado fauna and flora.

Occurrence: Post-Laramie (in my opinion), Black Buttes, Wyo. Laramie formation, Hoyt's coal mine, near Golden, and Marshall's coal mine, both in Boulder County, Colo.

Ficus planicostata magnifolia Knowlton, n. var.

Plate X, figure 3.

Ficus planicostata magnifolia Knowlton [nomen nudum], U. S. Geol. Survey Bull. 696, p. 285, 1919.

Similar to the type but much larger, reaching 14 centimeters in length and 9 centimeters in width, slightly more pointed above and less evidently truncate below, but otherwise much the same.

This form is described as new with some hesitation. It clearly belongs to that group of species which includes *Ficus planicostata*, *F. cockerelli*, *F. speciosissima*, *F. leei*, and others. *Ficus cockerelli* differs from it in being very much larger and in having a deeply cordate base, which produces marked differences in the nervation; *F. leei* differs in size and shape, being smaller and more elongate, and in a number of minor particulars of nervation.

It is of course quite true that difference in size is an unreliable criterion on which to base specific or even varietal distinction, provided there is agreement in other particulars, but in the present case it is thought that the differences are sufficient to warrant keeping these leaves from identification with the typical *F. planicostata*.

Occurrence: Laramie formation, Marshall, Colo., half a mile south of railroad station, in first draw north of white sandstone bluff, just above the highest coal of the region, collected by F. H. Knowlton and G. C. Martin, 1908.

Ficus praeplanicostata Knowlton, n. sp.

Plate XXII, figure 2.

Ficus praeplanicostata Knowlton [nomen nudum], U. S. Geol. Survey Bull. 696, p. 285, 1919.

Leaf coriaceous, elliptical-obovate, apparently rounded below to a more or less distinctly wedge-shaped base and narrowed above in like degree to an obtusely acuminate apex; margin perfectly entire; midrib rather slender, perfectly straight; apparently three-ribbed from or near the base, the lateral ribs slender, at an acute angle, somewhat curving upward, ascending nearly to the top of the blade, and joining the lowest secondary just within the margin; lateral ribs with seven or eight secondary branches on the outside, each of which arises at an acute angle, curves slightly upward and joins the one next above just at the margin; secondaries on the midrib four or five pairs, scattered, strongly alternate, each passing upward practically parallel to the lateral ribs and joining the one next above, the upper pair arching completely around and joining the midrib near the apex of the blade; nervilles very numerous and conspicuous, mainly percurrent but also broken, approximately at right angles to the midrib.

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[89] Lesquereux, Leo, op. cit. (Tertiary flora), pl. 31, fig. 9.

[90] Ward, L. F., Types of the Laramie flora: U. S. Geol. Survey Bull. 37, p. 39, pl. 21, fig. 3, 1887.

This species, of which a very good figure is given, appears to be represented only by this example. It lacks the basal portion and most of the margin on one side, but as nearly as can be made out it is about 10 or 12 centimeters in length and about 6 centimeters in width at the broadest point, which seems to be a little above the middle. The nervation is very distinct and regular, as described above.

This species is undoubtedly most closely related to *Ficus planicostata* Lesquereux,[91] from which it differs in its apparently wedge-shaped base, more pointed apex, and more erect, relatively slenderer nervation, for it is in a way intermediate between this and Lesquereux's variety *clintoni*, but it appears sufficiently distinct from *F. planicostata* by the characters mentioned, and it is clearly distinct from the variety *clintoni*. Additional material may give evidence of variation in the direction of the typical form, but until that is forthcoming this may stand as a distinct though obviously closely related variety.

Occurrence: Laramie formation, Coal Creek, Boulder County, Colo.

Ficus impressa Knowlton, n. sp.

Plate VII, figures 1–3; Plate XVI, figure 3.

Ficus impressa Knowlton [nomen nudum], U. S. Geol. Survey Bull. 696, p. 278, 1919.

Leaves of thick texture, uniform size, and ovate or elliptical outline, rounded and truncate or very obtusely wedge-shaped at the base, obtusely pointed at the apex; margin entire; nervation deeply impressed, three-ribbed from the base of the blade, the midrib slightly the strongest, with about three pairs of strong camptodrome secondaries above the middle; lateral ribs at an angle of 50° or 60°, each with five to seven secondary branches on the outside, these camptodrome and arching just inside the margin; nervilles very numerous, strong, often broken.

This species is represented by a considerable number of examples, one of which is nearly perfect. They are about 7 centimeters in length and vary in width from 3.5 to 6 centimeters.

This species is also the type of *Ficus planicostata* Lesquereux, from which it differs in being narrower, more elliptical, and less truncate at the base. The lateral ribs are at a slightly more acute angle, and both these and the secondary branches are less regular; the nervilles are the same in both.

Occurrence: Laramie formation, Marshall, Colo., collected by Arthur Lakes, 1890.

Ficus coloradensis Cockerell.

Plate XXII, figure 1.

Ficus coloradensis Cockerell, Torreya, vol. 10, p. 223, 1910.

Ficus irregularis (Lesquereux) Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1874, p. 304, 1876; idem, Bull., vol. 1, p. 368, 1876; Tertiary flora: U. S. Geol. Survey Terr. Rept., vol. 7, p. 196, pl. 34, figs. 4–7, 1878; Harvard Coll. Mus. Comp. Zoology Bull., vol. 16, p. 50, 1888. [Homonym, Miquel, 1867.]

Ward, U. S. Geol. Survey Sixth Ann. Rept., p. 552, pl. 44, fig. 4, 1886 [not fig. 5, which=*Rhamnus goldianus*]; U. S. Geol. Survey Bull. 37, p. 38 pl. 20, fig. 4, 1887 [not fig. 5, which=*Rhamnus goldianus*].

Knowlton, U. S. Geol. Survey Bull. 163, p. 51, 1900.

Ulmus? irregularis Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1872, p. 378, 1873.

A good deal of confusion seems to be current regarding the distribution of this species. It was originally described under the name *Ulmus? irregularis* from specimens found in the Denver beds at Golden, Colo., and subsequently was reported by Lesquereux from Point of Rocks, Black Buttes, and Carbon, Wyo. The type specimens figured by Lesquereux in the "Tertiary flora" (Pl. XXXIV, figs. 4–7) are preserved in the United States National Museum and are before me. The originals of Lesquereux's figures 5, 6, and 7 (Museum Nos. 296, 297, 831) are all in the andesitic material characteristic of the Denver beds, and additional examples are to be found in subsequent collections from this area. The original of his figure 4 (Museum No. 295) is recorded as coming from Carbon, Wyo., but later collections from this locality do not seem to contain it.

The material upon which Lesquereux based his statement of the abundant presence of *F. irregularis* at Black Buttes is not to be found in the Museum collections, and as this species has not been found there by any of the subsequent collectors, Lequereux's statement may be set down as extremely doubtful and not entitled to any consideration.

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[91] Lesquereux, Leo, The Tertiary flora: U. S. Geol. Survey Terr. Rept., vol. 7, pl. 31, 1878.

The status of *F. irregularis* at Point of Rocks, Wyo., is hardly more satisfactory. The single specimen figured by Lesquereux[92] as from this locality is No. 295a of the United States National Museum collection and represents only the petiole and extreme basal portion of a leaf. I admitted this species in my "Flora of the Montana formation" on the basis of this example alone, for none other seems to have been found, but I doubt the wisdom of so doing without further reservation. So far as can be made out from so small a portion it might have belonged to *F. irregularis*, and on the other hand it would be equally hard to exclude it from a number of other species of similar size. In any event, if admitted as a member of the Montana flora, its status as above outlined should be distinctly recalled and weighed accordingly.

As noted in the synonymy, one of the two leaves figured by Ward is with little doubt *Rhamnus goldianus*. It has a slightly but distinctly heart-shaped base with a number of short tertiaries going out from the lower side of the lowest pair of secondaries, exactly as Lesquereux described for *R. goldianus* and quite unlike typical *Ficus irregularis*. The latter has a wedge-shaped base, with no tertiaries on the lower side of the lowest pair of secondaries.

In the material collected by Ward in 1883 and figured but not described is one specimen obtained in white sandstone at a point 1¼ miles southeast of Golden and therefore probably in the true Laramie; and a leaf which can hardly be distinguished has been found at Marshall, Colo.

Occurrence: Laramie formation, Marshall and 1¼ miles south of Golden, Colo. Denver formation, Golden, Colo. (types). "Upper Laramie," Carbon, Wyo. (doubtful). Mesaverde formation, Point of Rocks, Wyo. (doubtful).

Ficus dalmatica Ettingshausen.

Plate XXI, figure 9; Plate XXII, figure 5.

Ficus dalmatica Ettingshausen, Eocene flora of Mount Promina, p. 29, pl. 7, fig. 11, 1855.

Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1874, p. 303, 1875; Tertiary flora: U. S. Geol. Survey Terr. Rept., vol. 7, p. 199, pl. 63, figs. 3-5, 1878.

Knowlton, U. S. Geol. Survey Bull. 163, p. 51, pl. 8, fig. 4, 1900.

This European species was identified by Lesquereux with specimens from Point of Rocks, Wyo. One of these specimens (No. 294, U. S. Nat. Mus., original of Lesquereux's Pl. LXIII, fig. 4) is in the United States National Museum and agrees very closely with the figures of this species in Ettingshausen's paper above cited, though it is perhaps to be doubted if they are really identical.

In the collections from Coal Creek there is a single leaf—the one here figured—that is almost the exact counterpart of figure 4 of Lesquereux's Plate LXIII. Another leaf shown in Plate XXII, figure 5, also from Coal Creek, is referred here with some question. It is not well preserved, and its characters are made out with difficulty.

Occurrence: Laramie formation, Coal Creek, Boulder County, Colo. Mesaverde formation, Point of Rocks, Wyo.

Ficus neodalmatica Knowlton, n. sp.

Plate VII, figure 6.

Ficus neodalmatica Knowlton [nomen nudum], U. S. Geol. Survey Bull. 696, p. 283, 1919.

Leaf of small size and firm texture, ovate-cuneate, broadest at or near the middle, from which it narrows regularly to the base and above to the obtusely acuminate apex; midrib very thick, especially below; lower pair of secondaries arising at the base of the blade, at a much more acute angle than the ones above, passing up to or above the middle of the leaf and there joining by a broad loop with the pair next above; upper secondaries about four pairs, alternate, at irregular distances, camptodrome, each joining the one above by a broad loop well inside the margin and with a series of loops outside; nervilles sparse, mainly broken.

The leaf figured is nearly perfect. It is slightly unequal sided, being ovate-cuneate, with a wedge-shaped base and an obtusely acuminate apex. It is 6.5 centimeters in length and 3.5 centimeters in width at a point a little above the middle of the blade. This species is undoubtedly most closely related to what Lesquereux has figured from Point of Rocks, Wyo., as *Ficus dalmatica* Ettingshausen.[93] It differs from that form in its larger size and broader outline, but in the nervation they are of the same type, as may be seen on comparing especially Lesquereux's figure 4 with the present species.

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[92] Op. cit. (Tertiary flora), pl. 63, fig. 9.

[93] Lesquereux, Leo, The Tertiary flora: U. S. Geol. Survey Terr. Rept., vol. 7, pl. 63, figs. 3-5, 1878.

Occurrence: Laramie formation, cut on Moffat railroad (Denver & Salt Lake) about 6 or 8 miles north of Golden, Colo., collected by A. C. Peale, 1908.

Ficus? leyden Knowlton, n. sp.

Plate XIV, figure 1.

Ficus? leyden Knowlton [nomen nudum], U. S. Geol. Survey Bull. 696, p. 283, 1919.

Size and complete outline not known, but apparently very unequal sided; base truncate; margin entire; nervation palmate from the extreme base of the blade, the ribs five, very unequally distributed; the first rib on the narrow side of the blade is nearly straight and has four or five slender branches on the outside; the next rib, which may be called the midrib, is slightly larger than either of the others, with several pairs of thin secondary branches in the upper part; the other ribs supply the full side of the blade and have several branches on the outside which are probably camptodrome, but as the margin is missing at this point it is impossible to be positive; finer nervation obsolete.

This leaf has the appearance of having been sessile, and the narrow side was naturally the upper side. It is so well shown in the figure that no other description is necessary.

It is perhaps doubtful if this leaf should be referred to *Ficus*, but the generic affinity is believed to be with what Newberry called *Ficus? alaskana*,[94] from the Kenai formation of the Cook Inlet region of Alaska, especially the one shown in the figure cited. This has the five ribs in the somewhat unequal sided leaf, but the form under consideration differs in being truncate instead of heart-shaped at the base and in being very unequal sided, and this affects the direction of the ribs. It is possible that this is only an individual variation or abnormal form of *Ficus cockerelli*, though the texture of the leaf and the absence of finer nervation mark it as distinct.

Occurrence: Laramie formation, Leyden Gulch, about 6½ miles north of Golden, Colo., collected by A. C. Peale.

Ficus post-trinervis Knowlton, n. sp.

Plate VI, figures 1, 2.

Ficus post-trinervis Knowlton [nomen nudum], U. S. Geol. Survey Bull. 696, p. 285, 1919.

Leaves of firm texture, ovate or ovate-elliptical, about equally narrowed to both base and apex, three-ribbed from the very base to the blade, all the ribs of equal size, the lateral ones passing up for two-thirds or three-fourths the length of the blade, curving in in the upper portion; secondaries few, alternate, above the middle of the leaf, camptodrome; finer nervation not retained.

The two leaves figured illustrate this species very well, though neither is quite perfect. They are 6 or 7 centimeters in length and about 3 centimeters in width. One has the petiole preserved for a length of 1 centimeter, but it is obviously broken. Where the petiole merges into the blade it splits into three equal ribs which divide the blade into four approximately equal areas.

This species is undoubtedly most closely related to *Ficus praetrinervis* Knowlton, from the Vermejo formation of southern Colorado. The leaves are much smaller than is usual in that species, are more nearly elliptical, and are not known to have secondary branches on the outside of the lateral ribs. The secondaries on the midrib start at a higher point than in *F. praetrinervis*, but this is perhaps a variable character. This species is also related to *F. cannoni*, described below, which, however, differs in its much smaller size and thinner lateral ribs or secondaries, which join the secondaries on the midrib near the middle of the blade.

Occurrence: Laramie formation, Cowan station, 10 miles southeast of Denver, Colo., collected by F. H. Knowlton, 1908.

Ficus cannoni Knowlton, n. sp.

Plate VI, figure 3; Plate X, figure 1.

Ficus cannoni Knowlton [nomen nudum], U. S. Geol. Survey Bull. 696, p. 272, 1919.

Leaves small, of firm texture, obovate-lanceolate, rather obtuse above, narrowly wedge-shaped below, perfectly entire; midrib very slender; secondaries about four or five pairs, the lower ones arising at the very base of the blade and running up for nearly or quite half the length of the leaf and joining the next pair of secondaries, which arise high above the base; other secondaries thin, at an angle of about 45°, considerably curved upward, camptodrome, each joining the one next above; finer nervation not retained.

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[94] Newberry, J. S., U. S. Geol. Survey Mon. 35, pl. 55, fig. 2, 1898.

This species is represented by several examples, two of which have been figured. The larger one is about 5 centimeters long and nearly 2 centimeters broad; the other is about 4 centimeters long and 1.5 centimeters wide. It may be distinguished at once by its obovate shape, narrowly wedge-shaped base, and thin lower secondaries, which run up and join the next pair of secondaries, the latter originating near the middle of the blade.

This species is of the type of *Ficus trinervis* (Ward) Knowlton, *F. praetrinervis* Knowlton, from the Vermejo formation, and *F. post-trinervis* of this report. From all these it differs in its smaller size and more markedly obovate outline. It was at one time thought that these specimens might be very small, narrow leaves of *F. praetrinervis*, but as that species is usually very abundant where it occurs at all, intermediate forms connecting the two should be found, but they have not, and so *F. cannoni* is considered as undoubtedly distinct.

This species is named in honor of George L. Cannon, of Denver, who has long been identified with the study of the geology of the Denver Basin.

Occurrence: Laramie formation, Cowan station, 10 miles southeast of Denver, Colo. (Pl. VI, fig. 3); collected by F. H. Knowlton, 1908; Popes Bluff, just north of Pikeview, Colo. (sec. 14, T. 13 S., R. 67 W.), collected by A. C. Peale and M. I. Goldman, 1908.

Ficus navicularis Cockerell.

Plate VI, figures 4, 5; Plate XI, figures 3-5.

Ficus navicularis Cockerell, Am. Mus. Nat. Hist. Bull., vol. 24, p. 89, 1908; Torreya, vol. 9, p. 141, figs. A, C (in text), 1909.

Ficus lanceolata Heer, Flora tertiaria Helvetiae, vol. 2, p. 62, pl. 81, figs. 2-5, 1856. [Homonym, Buchenau-Hamilton, 1814.]

Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1871, p. 300, 1872; Tertiary flora: U. S. Geol. Survey Terr. Rept., vol. 7, p. 191, pl. 28, figs. 1-5, 1878. [Figures 1-5 reproduced on Pl. XI, figs. 3-5.]

The first American specimens referred to *Ficus lanceolata* Heer were mentioned by Lesquereux in 1871 [1872], having probably been collected the previous year. He wrote as follows of the collection of which they form a part:

> Hard, shaly, fine-grained whitish sandstone. About the same consistence and color as the specimens from Carbon station. The precise locality is unknown, the labels having been lost or forgotten.

Most of this collection is still preserved in the United States National Museum, and, although it was originally stated to be from an unknown locality, the next time—and in fact at all subsequent times—it was mentioned it was said by Lesquereux to have come from the Green River formation. The nature of the matrix entirely precludes the probability of this being true, a view further confirmed by the other species in the collection, as well as by the geologic distribution subsequently shown for the various species.

Other specimens from Willow Creek, in Middle Park, and from Florissant, Colo., have been referred to this species, but most of these specimens can not now be found. The only one that I have been able to see is a very fragmentary leaf from Florissant that may or may not belong to this species, and in any event it should have little weight in any scheme of geologic distribution, unless other clearly identical material can be obtained. In the very extensive collections from Florissant studied by Cockerell and me it has not been observed with certainty.

Ficus lanceolata was described by Heer from material obtained in the Swiss Miocene in 1856, but, as set forth in the synonymy above, this name is preoccupied by a living oriental species named in 1814, and consequently the species was renamed by Cockerell *Ficus navicularis*. This name, however, should be applied only to the American specimens that had been referred to *Ficus lanceolata* Heer, for a comparison of the figures given by Heer and Lesquereux leads to the conclusion that they are not conspecific. The American leaves are long, narrowly lanceolate, with many close, parallel secondaries, whereas the leaves from the Swiss Miocene are not only larger but incline to the obovate-lanceolate and have fewer secondaries, which are scattered, much curved upward, and very markedly camptodrome. It is probable that the European leaves should be given a new name, for they can not be called *F. lanceolata* and they appear to differ from the American *F. navicularis*.

I was at one time inclined to refer a part of *Ficus arenacea* Lesquereux [95] to what was then called *F. lanceolata*, but, as Cockerell [96] has pointed out, it may be distinguished by its broader and strongly inequilateral base. It was a part of the same collection from an unknown locality and is certainly very close to *F. navicularis*.

Ficus navicularis belongs to that type of nondescript, narrow leaves that are difficult to identify with certainty unless they are exceptionally well preserved, a condition unfortunately far from being usual in the Laramie material. It is on this account that the species (usually under the name *F. lanceolata*) has been reported from a number of localities, and as the material is often fragmentary or the nervation poorly preserved, some of these identifications are probably open to more or less question. Thus, a narrow lanceolate form from the Vermejo formation of the Starkville mine at Starkville, Colo., has been described under the name *Ficus? starkvillensis* Knowlton.[97] *Ficus navicularis* has also been reported from beds described as of Mesaverde age in the vicinity of Lay, Colo.

The material from Marshall embraces a number of lanceolate leaves that are referred to *F. navicularis* with little hesitation. The one shown in Plate VI, figure 4, is of approximately the same size and shape as that shown in figure 4 of Plate XXVIII of the "Tertiary flora" and differs only slightly in the secondaries. The fragmentary leaf shown in Plate VI, figure 5, is of the same type as Lesquereux's figure 3 but is a little larger.

Occurrence: Laramie formation, types from an unknown locality, subsequently collected from the Marshall coal mine, Marshall, Colo., by Arthur Lakes, 1890.

Ficus multinervis? Heer.

Plate XII, figures 3, 3a, 4.

Ficus multinervis Heer. Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1871, p. 300, 1872; Tertiary flora: U. S. Geol. Survey Terr. Rept., vol. 7, p. 194, pl. 28, figs. 7, 8. [Lesquereux's figures are here reproduced.]

This species was described by Heer [98] in 1856 from specimens obtained in the Miocene of Switzerland. The American specimens referred by Lesquereux to this species have the same history as *Ficus lanceolata* (now *F. navicularis*)—that is, the source of the original specimens is not known. They have likewise usually been referred to the Green River formation up to the present time.

The collection from the coal mine on Coal Creek, Boulder County, Colo., made by Arthur Lakes in 1890 contains a number of fragments that seem to belong to this form. They are similar in shape to *Ficus navicularis* but have the more numerous secondaries at a more acute angle of divergence.

Occurrence: Laramie formation, Coal Creek, Boulder County, Colo., collected by Arthur Lakes, June, 1890.

Ficus denveriana? Cockerell.

Plate XII, figure 5.

Ficus denveriana Cockerell, Torreya, vol. 10, p. 224, 1910. Knowlton, U. S. Geol. Survey Prof. Paper 101, p. 302, pl. 76, figs. 1, 2, 1918.

Ficus spectabilis Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1872, p. 379, 1873; Tertiary flora: U. S. Geol. Survey Terr. Rept., vol. 7, p. 199, pl. 33, figs. 4–6, 1878; Harvard Coll. Mus. Comp. Zoology Bull., vol. 16, p. 50, 1888; U. S. Nat. Mus. Proc., vol. 11, p. 25, 1888. [Homonym, Kunth and Bouché, Annales sci. nat., 3d ser., vol. 7, p. 235, 1847.]

This species is essentially a Tertiary form, having been first described from material found in the Denver formation at Golden, Colo. It is abundant in the Denver formation in the Denver Basin and was subsequently found in beds supposed to be of the same age in Middle Park and was also shown to be abundant in the Raton formation of the Raton Mesa region.

It is very rare, if indeed it is present at all, in the Laramie formation. It was first noted by Lesquereux [99] in a small collection from the old Franceville coal mine, a few miles southeast of Colorado Springs, Colo., though it is not contained in collections made at the same locality in 1908. The single, somewhat fragmentary leaf here figured was obtained by Peale and Goldman near the coal in Popes

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[95] Lesquereux, Leo, The Tertiary flora: U. S. Geol. Survey Terr. Rept., vol. 7, pl. 29, figs. 1, 4, 1878 (not figs. 2, 3).

[96] Cockerell, T. D. A., Am. Mus. Nat. Hist. Bull., vol. 24, p. 89, 1908.

[97] Lee, W. T., and Knowlton, F. H., U. S. Geol. Survey Prof. Paper 101, p. 262, pl. 38, fig. 9, 1918.

[98] Heer, Oswald, Flora tertiaria Helvetiae, vol. 2, p. 63, pl. 81, figs. 6–10, 1856.

[99] Lesquereux, Leo, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1873, p. 203, 1874.

Bluff, west of Pikeview, Colo., in sec. 14, T. 13 S., R. 67 W. It is of about the same size as the largest of the types of this species figured by Lesquereux,[1] but it is more obtuse at the apex and apparently has fewer secondaries and these at a slightly more acute angle. The basal portion can not be compared with the types. Possibly this leaf should not be referred to *Ficus denveriana*, though it undoubtedly approaches that species most closely.

Occurrence: Laramie formation, Popes Bluff, west of Pikeview, Colo. (sec. 14, T. 13 S., R. 67 W.), collected by A. C. Peale and M. I. Goldman, 1908. Denver formation (types), Golden, Colo. Raton formation, Raton Mesa region of Colorado and New Mexico.

Ficus crossii Ward.

Plate XI, figure 2.

Ficus crossii Ward, U. S. Geol. Survey Sixth Ann. Rept., p. 552, pl. 44, fig. 7, 1886; U. S. Geol. Survey Bull. 37, p. 39, pl. 21, fig. 2, 1887.

Ficus uncata Lesquereux. Knowlton, U. S. Geol. Survey Bull. 152, p. 105, 1898.

The type specimen of this species (U. S. Nat. Mus. No. 4106) is before me. Although it is described by Ward as being "preserved with considerable fidelity," a careful study discloses the fact that Ward's figure of it is somewhat in error. None of the basal portion and indeed very little of the margin is preserved. The blade alone was probably over 8 centimeters in length, and it may have been longer. The midrib has the appearance of being unusually thick for a leaf of this size, and it was largely on this account that I was at one time inclined to refer this leaf to *Ficus uncata*, which has an especially strong midrib.

The later collections from Golden included the specimen here figured, which is believed to be the same as *Ficus crossii*. It is a longer leaf than Ward's figure of *F. crossii* would imply, but they were probably really of the same dimensions. The present leaf, which is also ovate-oblong in outline, was about 9 centimeters long and nearly 6 centimeters wide. The midrib is very thick below but becomes thinner above. There are 10 or 11 pairs of secondaries, which arise at an angle of about 70° and are abruptly camptodrome near the margin. The lower secondary has a few very short camptodrome branches on the outside. The nervilles are seen to be numerous, strong, and oblique to the secondaries, as in *F. crossi*. They seem best removed from *Ficus uncata*.

These leaves suggest *Rhamnus goldianus* Lesquereux,[2] but they are more wedge-shaped at the base and, moreover, the secondaries curve near the margins in a very different manner.

Occurrence: Laramie formation (type), Golden, Colo., collected by Whitman Cross, for whom it is named. The specimen figured was collected by L. F. Ward 1½ miles southwest of Golden, Colo.

Ficus cowanensis Knowlton, n. sp.

Plate VIII, figure 6; Plate IX, figures 2, 3.

Ficus cowanensis Knowlton [nomen nudum], U. S. Geol. Survey Bull. 696, p. 273, 1919.

Leaves of large size and thick texture; ovate-lanceolate, or perhaps narrowly obovate-lanceolate, with long, wedge-shaped base and rather obtuse apex; margin perfectly entire; midrib extremely thick, especially below; secondaries few—about six or seven pairs—far apart, relatively very thin, at an angle of approximately 30° or 40°, apparently camptodrome; nervilles numerous, very thin, at nearly right angles to the secondaries.

This species is represented by several examples, all of which are fragmentary or more or less distorted. The length, so far as can be made out, is about 15 centimeters and the width 7 or 8 centimeters. The secondaries are exceptionally slender for a leaf of this size.

Occurrence: Laramie formation, Cowan station, 10 miles south of Denver, Colo., collected by F. H. Knowlton.

Ficus berryana Knowlton, n. sp.

Plate XI, figure 1.

Ficus berryana Knowlton [nomen nudum], U. S. Geol. Survey Bull. 696, p. 272, 1919.

Leaf thin in texture, broadly ovate, very abruptly rounded and truncate at the base, deltoid-acuminate at the apex; margin entire; nervation very light, triple-nerved from the base of the blade; midrib straight, with about two pairs of alternate, apparently camptodrome secondaries; lateral ribs at an angle of approximately 45°, thin, passing up about half the length of the leaf; finer nervation obsolete.

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[1] The Tertiary flora: U. S. Geol. Survey Terr. Rept., vol. 7, pl. 33, fig. 5, 1878.

[2] Lesquereux, Leo, The Tertiary flora: U. S. Geol. Survey Terr. Rept., vol. 7, pl. 53, figs. 4-8, 1878.

The single example figured is all that was observed of this species. It is 5.5 centimeters long and a little over 4.5 centimeters wide. It appears to be closely related to *Ficus ovatifolia* Berry,[3] from the Eutaw formation of McBrides Ford, Ga. It is, however, more truncate at the base and more obtuse at the apex, and the lateral ribs do not ascend as high as in the Eutaw form.

This species is named in honor of Edward Wilber Berry, of Johns Hopkins University.

Occurrence: Laramie formation, Marshall, Colo., railroad cut between old and new stations, collected by A. C. Peale, 1908.

Ficus arenacea Lesquereux.

Plate X, figures 2, 4; Plate XXI, figure 9.

Ficus arenacea Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1871, p. 300, 1872; Tertiary flora: U. S. Geol. Survey Terr. Rept., vol. 7, p. 195, pl. 29, figs. 1, 4, 5, 1878.

Ficus lanceolata Heer. Knowlton, U. S. Geol. Survey Bull. 152, p. 102, 1898.

The early history of this species is the same as that of *Ficus lanceolata* (now *F. navicularis*, q. v.)—that is, it is a part of the collection from an unknown locality, the original labels, according to Lesquereux, "having been lost or forgotten." The matrix is a hard, shaly, fine-grained whitish sandstone, and although it was subsequently supposed to have come from the Green River formation it probably came from the Laramie. In any event, the two fragmentary leaves from the Laramie at Marshall here figured are not to be distinguished from figure 4 of Plate XXIX of Lesquereux's "Tertiary flora," and the species may now take definite place in the Laramie flora.

Occurrence: Laramie formation, Marshall, Colo., collected by Arthur Lakes, 1890.

Ficus? apiculatus Knowlton, n. sp.

Plate XI, figure 6.

Ficus? apiculatus Knowlton [nomen nudum], U. S. Geol. Survey Bull. 696, p. 270, 1919.

Leaf membranaceous, ovate-lanceolate, being abruptly rounded below and prolonged above into a long, slender acuminate apex; margin entire; nervation consisting of a rather strong midrib and four or five pairs of thin, remote secondaries, which curve upward and follow the margin for a considerable distance; finer nervation very obscure.

This leaf, the only one observed, is nearly perfect, as it lacks only the basal portion. It is about 12 centimeters long and 3.5 centimeters wide and may be known by its ovate-lanceolate outline with long, slender tip and the few curving secondaries.

This species has the same shape of leaf and type of nervation as *Ficus populina* Heer,[4] from the Swiss Miocene, but it differs absolutely in the margin, which is entire in the present species and crenate in the European form. It is perhaps doubtful whether this leaf should be referred to *Ficus*.

Occurrence: Laramie formation, Cowan station, south of Denver, Colo., collected by F. H. Knowlton, 1908.

Order ARISTOLOCHIALES.

Family ARISTOLOCHIACEAE.

Aristolochia brittoni Knowlton, n. sp.

Plate XXIII, figures 3-5.

Aristolochia brittoni Knowlton [nomen nudum], U. S. Geol. Survey Bull. 696, p. 96, 1919.

Leaves of medium size, broadly reniform, with rounded lobes, a deep rounded sinus, entire margin, and abruptly acuminate or obtuse apex; petiole very thick; nervation palmately three-ribbed from the very base of the blade; midrib thick, especially below, becoming flexuose in the upper portion, three or four pairs of alternate secondaries above the middle, arising at an angle of approximately 35°, forking well below the margin, and each joining the one next above by a broad loop and with one or two series of loops outside; lateral ribs strong, arising at an angle of about 45°, passing upward, and joining the lowest secondary on the midrib by a broad loop, each with about four secondary branches on the outside, which arch and join similarly to the upper secondaries; the lowest pair of secondaries with about four tertiary anastomosing branches on the lower side, supplying the rounded lobes of the blade; nervilles strong, percurrent, forming large rectangular areas; ultimate nervation not preserved.

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[3] Berry, E. W., U. S. Geol. Survey Prof. Paper 84, pl. 19, figs. 5-7. 1914.

[4] Flora tertiaria Helvetiae, vol. 2, pl. 85, figs. 4, 5, 1856.

This fine species, which appears to be quite unlike anything before reported from the Laramie, is represented by the nearly perfect example figured and by another, much poorer specimen which has little but the margin preserved. The form is broadly reniform, entire leaf about 6.5 centimeters wide and about 5.5 centimeters long, exclusive of the petiole, which is 17 millimeters along and 2 millimeters in diameter. The leaf is characterized by the three strong palmate ribs, the central with three or four camptodrome secondaries, and the lateral with an equal number of tertiary branches, all the ultimate branches of secondaries and tertiaries anastomosing, and with one or two series of broad loops outside.

After a somewhat careful comparison of this species with both living and fossil leaves referred to the genus *Aristolochia*, there can be little doubt as to the correctness of this determination. Among the living species, for example, it has very much the same shape as *A. clematis* Linné and *A. hirta* Linné, both of the Old World, and in both form and nervation it approaches the American *A. tomentosa* Sims.

Among the fossil species described, the one under discussion somewhat resembles *A. aesculapi* Heer,[5] but is a little larger. It is also considerably like *A. cordifolia* Newberry,[6] from the Fort Union formation of Montana, which differs in being longer than broad and in having five ribs springing from the top of the petiole.

Among the specimens from Marshall's mine is a fragment of the upper portion of a leaf that is referred with some hesitation to this species. It was a somewhat larger leaf, with a slightly more obtuse apex and a relatively thicker midrib. It bears about four pairs of alternate or subopposite, remote secondaries, which arch by a broad curve far within the margin and are provided with two or three distinct series of large loops outside. There are also intermediate secondaries which anastomose with the main secondaries by irregular rectangular areas. This is certainly a leaf of the same type as that first described and hardly differs except as regards the intermediate secondaries and the more irregular nervilles. It may be a different but closely related species, but it seems best, in the light of our present knowledge, to regard them as identical.

This species is named in honor of Dr. N. L. Britton, director of the New York Botanical Garden, by whom the specimens were collected.

Occurrence: Laramie formation, Coal Creek and Marshall's mine, Boulder County, Colo., collected by N. L. Britton about 1880.

Order RANALES.

Family NYMPHAEACEAE.

Nelumbo tenuifolia (Lesquereux) Knowlton.

Plate XXVI, figure 7.

Nelumbo tenuifolia (Lesquereux) Knowlton, U. S. Geol. Survey Bull. 696, p. 407, 1919.

Nelumbium tenuifolium Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1873, pp. 382, 402, 1874; idem for 1876, p. 514, 1878; Tertiary flora: U. S. Geol. Survey Terr. Rept., vol. 7, p. 253, pl. 46, fig. 3, 1878.

The type specimen of this species is preserved in the United States National Museum (No. 372, by error in the catalogue, 472). It is very indistinct, and the figure of it in the "Tertiary flora" is far from accurate. The only part of the true margin preserved is a fragment hardly 3 centimeters in extent shown in the upper left-hand portion of the figure. A careful examination of the specimen fails to show the margin in the lower portion, as given in the figure. This proves that the leaf was larger than appears from the drawing. It has thin ribs, as described by Lesquereux, and the whole leaf appears to have been of thin texture. In the original description Lesquereux states that the leaf is "exactly round, peltate from the middle, and 8 or 9 centimeters in diameter." As noted above, the type specimen is larger than the description calls for, being fully 10 centimeters in diameter. The ribs are 13 in number, but this feature is of little or no specific significance.

This species is most closely related to *Nelumbo lakesiana* (Lesquereux) Knowlton,[7] a well-known Denver species, from which it differs in its obviously thin texture, thin ribs, and smooth surface.

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[5] Heer, Oswald, Flora tertiaria Helvetiae, vol. 2, p. 104, pl. C. fig. 11, 1856.

[6] Newberry, J. S., U. S. Geol. Survey Mon. 35, pl. 40, fig. 7, 1898.

[7] Lesquereux, Leo, The Tertiary flora: U. S. Geol. Survey Terr. Rept., vol. 7, p. 252, pl. 46, figs. 1, 2, 1878.

In the collection from Erie, Colo., there is a single example (here figured) which appears to belong with *N. tenufolia*. It is folded around on both sides of a thin piece of matrix and appears to have been a thin, delicate leaf. Its diameter is about 10 centimeters; it has the same number of ribs as the type specimen. The margin is gently undulate, and the ribs are forked or branched some distance below the margin. The finer nervation is obscure.

Occurrence: Laramie formation, Erie, Colo., collected by N. L. Britton about 1885. Denver formation, Sand Creek, 15 miles east of Denver, Colo., collected by A. Gardner.

Family MAGNOLIACEAE.

Magnolia marshalli Knowlton, n. sp.

Plate XXI, figure 10.

Magnolia marshalli Knowlton [nomen nudum], U. S. Geol. Survey Bull. 696, p. 374, 1919.

Leaf oblong-lanceolate, with an obtuse apex and an obtusely wedge-shaped base; midrib straight, thick; secondaries about 15 pairs, alternate or a few subopposite, emerging at an angle of 40° or 45°, running with a slight upward curve to a point within one-fifth of their length from the margin, where each arches around and joins the one next above by an even, regular loop, from the outside of which smaller tertiaries are sent toward the margin; nervilles strong, percurrent, at right angles to the secondaries; finer nervation obsolete.

This fine leaf is 10.5 centimeters long and 3.5 centimeters wide at the broadest point, which is perhaps a little above the middle of the leaf. From the broadest point it tapers gradually to a rather obtuse apex and in about the same manner to the base. The petiole is not preserved. The midrib is very thick and prominent.

This leaf is referred to *Magnolia* with little hesitation. In outline it is very similar to a number of living species, as, for example, some of the cultivated forms of *M. grandiflora* Linné, young leaves of *M. umbrella* Linné, and particularly *M. pealii* King, a large tree found in Upper Assam, India. Its relation with *M. pealii* is very close, indeed, for it has the exact outline—except the taper-pointed apex—and much the same nervation. In nervation *M. marshalli* has clearly the characters of *Magnolia*, as shown by the figure.

Among fossil species of the Laramie and post-Laramie formations the present species approaches most closely *M. attenuata* Lesquereux,[8] differing by being much smaller and narrower. It also somewhat resembles *M. dayana* (Lesquereux) Cockerell, from the auriferous gravels of California,[9] from which it differs in being only half the size and relatively broader and less wedge-shaped at base.

Occurrence: Laramie formation, Marshall's mine, Boulder County, Colo., collected by Arthur Lakes, 1890.

Magnolia lakesii Knowlton, n. sp.

Plate XIII, figure 2.

Magnolia lakesii Knowlton [nomen nudum], U. S. Geol. Survey Bull. 696, p. 373, 1919.

Leaf of firm texture, broadly elliptical, almost oval, abruptly rounded in about the same degree to base and apex; margin perfectly entire; midrib strong below, becoming much thinner above, straight; secondaries four or five pairs, very thin, opposite or subopposite, at a very low angle, much curved upward, each joining the one next above and far inside the margin by a broad loop; nervilles few, mostly unbroken, oblique to the secondaries; finer nervation obsolete.

The leaf figured, which is one of several of its form, was about 7 centimeters long and 5.5 centimeters wide. It is nearly elliptical, with an abruptly rounded and truncate base. It is well marked by the thick midrib and few, thin secondaries arising at a very low angle and joining the ones above far from the margin of the blade.

Among the living American species of the genus *Magnolia* the leaf under consideration seems to be most closely related to *Magnolia acuminata* Linné, or more especially its variety *cordata*, which has been somewhat modified, apparently by long cultivation. The fossil leaf differs in being more nearly elliptical and in having fewer secondaries, but its general appearance is much like that of the species mentioned.

This species has some resemblance to what was called *Ficus haguei* Knowlton,[10] from the

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[8] The Tertiary flora: U. S. Geol. Survey Terr. Rept., vol. 7, p. 250, pl. 45, fig. 6, 1878.

[9] Harvard Coll. Mus. Comp. Zoology Mem., vol. 6, pl. 6, fig. 4, 1878.

[10] Knowlton, F. H., Fossil flora of the Yellowstone National Park: U. S. Geol. Survey Mon. 32, pt. 2, pl. 90, fig. 3, 1899.

Miocene of the Yellowstone National Park, but it differs slightly in shape and more markedly in nervation. It is rather doubtful if *F. haguei* was correctly referred to the genus *Ficus*.

Occurrence: Laramie formation, Marshall, Boulder County, Colo., collected by Arthur Lakes, 1890.

Family ANONACEAE.

Anona coloradensis Knowlton, n. sp.

Plate XVIII, figure 4.

Anona coloradensis Knowlton [nomen nudum], U. S. Geol. Survey Bull. 696, p. 78, 1919.

Leaves evidently thin and membranaceous, narrowly ovate-lanceolate, very obtusely wedge-shaped at the base, long acuminate at the apex; margin perfectly entire; midrib strong, straight; secondaries about seven pairs, alternate, thin, at an angle of about 50°, much curved upward just along the borders; finer nervation obsolete.

The specimen figured is about 8 centimeters long and 2.75 centimeters wide and is perfect except for small areas at the extreme base and apex.

This species appears to be closely related to *Anona palmeri* Safford,[11] a recently described living species from the vicinity of Acapulco, Mexico, being especially like the larger uppermost leaves of that form. They are of the same size and shape and have the same character of nervation, about the only apparent difference being the fewer secondaries in *A. coloradensis*.

Three species of *Anona* from this country have thus far been described—*A. cretacea* Lesquereux,[12] from the Dakota sandstone; *A. robusta* Lesquereux,[12a] from the Laramie at Golden, Colo.; and *A. spoliata* Cockerell,[13] from the Miocene at Florissant, Colo. The Dakota species has never been figured. The original figure of *A. robusta*, the Laramie species, is reproduced in Plate XVII, figure 7. The Florissant species is smaller and very different in shape, being similar to the living *A. glabra* Linné, of Florida. The present species, if referable to this genus, belongs to quite another section than those above mentioned.

Occurrence: Laramie formation, Cowan station, 10 miles south of Denver, Colo., collected by F. H. Knowlton.

Anona robusta Lesquereux.

Plate XVII, figure 7.

Anona robusta Lesquereux, Cretaceous and Tertiary floras: U. S. Geol. Survey Terr. Rept., vol. 8, p. 124, pl. 20, fig. 4, 1883.

Leaf large, about 13 centimeters long, 6 centimeters broad below the middle, coriaceous, ovate-lanceolate, gradually narrowed to the pointed apex, abruptly rounded and truncate at the base, margin slightly undulate; median nerve very thick, especially below, straight; secondaries 12 or 13 pairs, strong, mainly alternate, close, parallel, very open or nearly at right angles toward the base, then gradually at a more acute angle, slightly curved upward, camptodrome; nervilles prominent, oblique to the secondaries, simple and continuous or anastomosing in the middle.

The type and so far as known the only specimen of this fine species is in the collection of the Museum of Princeton University (No. La. 74). It is preserved on the coarse white sandstone characteristic of the true Laramie in the vicinity of Golden, Colo. There is nothing to add to the description and well-executed figure given by Lesquereux.

Occurrence: Laramie formation, Golden, Colo., first sandstone hogback west of Tarr Hall.

Family LAURACEAE.

Laurus lanceolata Knowlton, n. sp.

Plate XXI, figure 7.

Laurus lanceolata Knowlton [nomen nudum], U. S. Geol. Survey Bull. 696, p. 346, 1919.

Leaf coriaceous, narrowly lanceolate or possibly oblanceolate, long and narrowly wedge-shaped at the base, somewhat unequal sided (apex destroyed); midrib relatively strong, especially below, perfectly straight; secondaries few (only four pairs showing in the specimen), opposite or subopposite, at an acute angle, passing up for long distances and but slightly curved, disappearing just at the margin; nervilles few and obscure, apparently unbroken and at right angles to the secondaries.

This species is represented by the single example figured, which unfortunately lacks the upper portion for an unknown length. The absence of the apical portion makes it impossible to determine the shape satisfactorily; it appears to be simply narrowly lanceolate, though it may be larger above, which would make it oblanceolate. The portion preserved is a little over 7 centimeters in length and a little under 1.5 centimeters in greatest width.

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[11] Safford, W. E., Contr. U. S. Nat. Herb., vol. 18, pl. 24, 1914.

[12] Lesquereux, Leo, The Cretaceous and Tertiary floras: U. S. Geol. Survey Terr. Rept., vol. 8, p. 77, 1883.

[12a] Idem, p. 124, pl. 20, fig. 4.

[13] Cockerell, T. D. A., Descriptions of Tertiary plants, II: Am. Jour. Sci., 4th ser., vol. 26, p. 542, fig. 7, 1908.

This species is quite distinct from anything previously noted in the Laramie and appears to find its closest relative in *Laurus oregoniana* Knowlton,[14] from the Mascall formation (Miocene) of the John Day Valley, Oreg. That species is very much larger than the leaf under discussion, being some 18 centimeters in length and 3.5 or 4.5 centimeters wide, but it has the same shape and general appearance. It differs slightly, however, in having the secondaries markedly alternate and the nervilles much broken.

Occurrence: Laramie formation, Coal Creek, Boulder County, Colo., mine on road near McNamara's, collected by Arthur Lakes, June, 1890.

Laurus lakesii Knowlton, n. sp.

Plate XXII, figure 6.

Laurus lakesii Knowlton [nomen nudum], U. S. Geol. Survey Bull. 696, p. 346, 1919.

Leaf of firm texture, lanceolate; about equally narrowed to both base and apex; midrib slender, straight; secondaries about six or seven pairs, alternate, at a low angle, camptodrome, arching close to the border; finer nervation forming quadrangular areolae.

This little leaf is about 6 centimeters long and 1.2 centimeters wide. The nervation is not very well preserved.

This species is of the same type as and pretty closely related to what Lesquereux [15] described and figured under the name *Laurus primigenia* Unger, mainly from Evanston, Wyo., but it is rather smaller and has fewer secondaries at a more acute angle of divergence.

Lesquereux mentions specimens from Black Buttes, Wyo., and Spring Canyon, Mont., which he at first considered identical with those subsequently described under the name *Laurus primigenia* Unger, but they were so fragmentary that he hesitated to place them together. It is possible that they may prove to be the same as the leaf here described.

The leaf described above as *Laurus lanceolata* is of about the same size and shape as the present one but differs markedly in its primary nervation.

Occurrence: Laramie formation, Coal Creek, Boulder County, Colo., collected by Arthur Lakes, 1890.

Laurus wardiana Knowlton.

Plate XVI, figure 1 (type).

Laurus wardiana Knowlton, U. S. Geol. Survey Bull. 152, p. 129, 1898.

Laurus ocoteoides Lesquereux, Tertiary flora: U. S. Geol. Survey Terr. Rept., vol. 7, p. 215, pl. 36, fig. 10, 1878; U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1876, p. 510, 1878. [Lesquereux's original figure of the type is here reproduced.] [Homonym, *Laurus ocoteaeoides* Massalongo, Synopsis florae fossilis senogalliensis, p. 57, pl. 24, fig. 3; pl. 40, fig. 1, 1858.]

The type of this fine species is preserved in the United States National Museum (No. 905) and is the only specimen ever obtained from the Laramie. It comes from the hard white sandstone at Golden, Colo., and therefore belongs in the Laramie.

Occurrence: Laramie formation, Golden, Colo. ?Dawson arkose, near Mosby, Colo., 30 feet above the coal.

Malapoenna louisvillensis Knowlton, n. sp.

Plate VII, figure 5.

Malapoenna louisvillensis Knowlton [nomen nudum], U. S. Geol. Survey Bull. 696, p. 379, 1919.

Leaf of medium size, narrowly ovate-lanceolate, apparently wedge-shaped at the base, narrowly acuminate at the apex; margin perfectly entire; midrib strong, straight; secondaries about three pairs, opposite or subopposite, at an angle of nearly 80°, the lower pair ascending far above the middle of the blade, with few outside branches, camptodrome; nervilles numerous, mainly broken or irregular; finer nervation forming a complete irregular network.

This species is represented by two fragmentary specimens, of which the larger and better is figured. As this specimen lacks both base and apex it is impossible to ascertain the length, though it must have been about 8 centimeters; the width is a little less than 3 centimeters.

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[14] U. S. Geol. Survey Bull. 204, p. 58, pl. 9, figs. 2, 3, 1902.

[15] Lesquereux, Leo, The Tertiary flora: U. S. Geol. Survey Terr. Rept., vol. 7, p. 214, pl. 36, figs. 5, 6, 8, 1878.

The smaller leaf could hardly have been over 6 centimeters in length.

In shape and size this species is near *Malapoenna cuneata* Knowlton,[16] from the Yellowstone National Park, but it differs essentially in the fewer, more acute-angled secondaries.

Occurrence: Laramie formation, dump of Rex mine No. 1, Louisville, Colo., collected by A. C. Peale, 1908.

Cinnamomum affine Lesquereux.

Plate VIII, figure 4; Plate XVII, figure 6.

Cinnamomum affine Lesquereux, Am. Jour. Sci., 2d ser., vol. 45, p. 206, 1868; U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1869 [reprint, 1873], p. 169; idem for 1872, p. 383, 1873; idem for 1873, p. 401, 1874; Tertiary flora: U. S. Geol. Survey Terr. Rept., vol. 7, p. 219, pl. 37, figs. 1–4, 7 [not fig. 5, which = *Ficus trinervis* Knowlton].

Knowlton, U. S. Geol. Survey Bull. 163, p. 59, pl. 14, fig. 2, 1900.

Cockerell, Torreya, vol. 9, p. 142, 1909.

For many years there has been much confusion concerning this species, but it is believed that there are now sufficient data at hand to clear up most of this uncertainty. *Cinnamomum affine* was named by Lesquereux[17] in 1868 and based on material from "Marshall's mine, near Denver," Colo., but it was neither described nor figured at that time. It was next mentioned the following year, when Hayden reproduced Lesquereux's article without change in his Third Annual Report of the United States Geological Survey of the Territories.[18] It was briefly alluded to but not described by Lesquereux[19] in discussing material from Marshall collected by himself in 1872. He was then undecided as to whether it was really distinct from his *Cinnamomum mississippiense*, from what is now known as the Wilcox group of the Gulf region. The following year Lesquereux[20] wrote of it as follows:

> From the comparison of a large number of specimens representing various forms of this species, it proves to be, as I had supposed, a mere variety of *C. mississippiense*. The species is common at Golden and found in the whole thickness of the North American lignitic measures.

Cinnamomum affine was first figured and properly described in the "Tertiary flora," published in 1878, or 10 years after it had been named. In discussing it Lesquereux says:

> I have been for a long time undecided in regard to the possible identity of this northern species with the beautiful *C. mississippiense* Lesquereux, communicated by Prof. E. W. Hilgard. From the larger size of the Mississippi leaf, more enlarged below the middle, its more rugose nervation, and the greater distance of the lateral nerves from the borders, I came to the conclusion that the leaves from Golden did represent a new species, or at least a diminutive variety of *C. mississippiense*.

In any event it was kept distinct from the Gulf species, and subsequent study of larger and better collections has confirmed this view.

Lesquereux expressed some doubt as to whether the specimen illustrated in figure 7 of Plate XXXVII in the "Tertiary flora" was conspecific with the others but added that as it was "found upon the same piece of shaly hard sandstone as the leaves of figures 1–3," it could not be separated from them. He further stated that the leaf depicted in his figure 4 was the specimen first obtained from Marshall's mine, Colo., and this is undoubtedly the type of the species. Unfortunately, neither this specimen nor the originals of Lesquereux's figures 1–3 can now be found in the United States National Museum, where they should be, and their location is unknown. However, the originals of figures 5 and 7 of Plate XXXVII of the "Tertiary flora" are in the Museum (No. 312) and came from Golden, Colo. They are preserved in hard whitish sandstone and hence are referable to the Laramie. So far as known this species has not subsequently been found at Golden.

Although a considerable collection from Marshall, the type locality, has been studied in the present connection, no examples of *Cinnamomum affine* were found, but Cockerell[21] reports finding it there in connection with what he has identified as *Juglans leconteana*. He states that it comes from a relatively high level.

The leaf shown in Plate VIII, figure 4, came from Cowan station, about 10 miles south of Denver, Colo.; it is indistinguishable from figures 1, 3, and 4 of Plate XXXVII of the "Tertiary flora."

In this connection it may be well to correct a number of erroneous references that have long been current regarding *Cinnamomum affine*. Thus, it was said to be very common in the

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[16] U. S. Geol. Survey Mon. 32, pt. 2, p. 726, pl. 92, figs. 2–4, 1899.

[17] Am. Jour. Sci., 2d ser., vol. 45, p. 206, 1868.

[18] Reprint, 1873, p. 196.

[19] U. S. Geol. and Geog. Survey Terr. Sixth Ann. Rept., p. 383, 1873.

[20] U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1873, p. 401, 1874.

[21] Cockerell, T. D. A., Torreya, vol. 9, p. 142, 1909.

Canon City field, but here it was confused with what has been described as *Ficus praetrinervis* Knowlton,[22] an exceedingly abundant form in the Vermejo formation. Lesquereux also stated that he had specimens of it from the Raton region of Colorado, but so far as now known it is not present there, the leaves mistaken for it being the larger *C. mississippiense*, which is confined to the Raton formation.[23]

The specimens from beds of post-Laramie age at Carbon, Wyo., are probably to be referred to *Populus* sp. undet., and the specimens obtained by Ward [24] at Black Buttes, Wyo., have been referred to *Ficus trinervis* Knowlton,[25] a species now known to be of wide distribution.

The final conclusion is reached that in no authenticated instance has *Cinnamomum affine* been found at a horizon younger than the true Laramie.

Occurrence: Laramie formation, Marshall, Colo. (types); Marshall, Colo., half a mile south of railway station, collected by F. H. Knowlton, 1908; Rex mine, Louisville, Colo., collected by A. C. Peale, 1908; Leyden Gulch, 6½ miles west of Golden, Colo., collected by A. C. Peale, 1908; Cowan station, 10 miles south of Denver, Colo., collected by F. H. Knowlton.

Cinnamomum laramiense Knowlton, n. sp.

Plate XXII, figure 3.

Cinnamomum laramiense Knowlton [nomen nudum], U. S. Geol. Survey Bull. 696, p. 170, 1919.

Leaf apparently rather thin in texture, very narrowly obovate-lanceolate, being broadest at a point somewhat above the middle, from which it tapers or rounds rather abruptly to a rounded apex and narrows downward to a wedge-shaped base; triple-nerved, the midrib slender, straight; lateral nerves or ribs of same size as midrib, opposite, arising high above the base and running nearly to the apex of the leaf, with very few branches on the outside; upper secondaries apparently only one pair, less than one-fourth the length of the blade from the apex, running to or near the margin. This leaf, of which only a single one seems to have been found, is about 9 centimeters long and a little less than 3 centimeters wide.

It is perhaps unwise to attempt the characterization of a species of *Cinnamomum* on a single specimen, but the one in hand seems to differ from others sufficiently to be worthy of independent rank, at least until further material can be obtained.

Among living species it is perhaps nearest to *C. cassia* Blume, except that it is relatively rather narrower below. Among fossil forms it approaches a number of species, especially *C. lanceolatum* as usually depicted from European sources. From that species, however, it appears to differ in having a more obtuse apex and only two pairs of secondaries on the midrib.

Occurrence: Laramie formation, Morrison, Colo., white sandstone near coal seam, collected by Arthur Lakes, 1890; Cowan station, 10 miles south of Denver, Colo., collected by F. H. Knowlton, 1908.

Order ROSALES.

Family PLATANACEAE.

Platanus platanoides (Lesquereux) Knowlton?

Plate XIII, figure 1.

Platanus platanoides (Lesquereux) Knowlton, U. S. Geol. Survey Bull. 152, p. 171, 1899.

Viburnum platanoides Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1874, p. 314, 1876; Tertiary flora: U. S. Geol. Survey Terr. Rept., vol. 7, p. 224, pl. 38, figs. 8, 9, 1878.

One of the original types of this species, illustrated in the "Tertiary flora," Plate XXXVIII, figure 8, is preserved in the United States National Museum collection (No. 327). It came, according to Lesquereux, from Black Buttes, Wyo. As indicated above, it was described under the name *Viburnum platanoides* and was regarded as being rather closely related to *Viburnum marginatum* (now *Platanus marginata*), from which it differs in having "less numerous, more open, lateral veins, whose branches are more curved in passing up to the borders, and especially by the enlarged truncate or subtruncate base of the leaves." The type specimen is rather fragmentary, but so far as known it has been accurately diagnosed by Lesquereux.

Platanus platanoides has since been found in beds of "Lower Laramie" (Medicine Bow) age in Carbon County, Wyo., and has been reported as doubtfully present in the Raton formation of southern Colorado.

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[22] U. S. Geol. Survey Prof. Paper 101, p. 263, pl. 41, figs. 1–4; pl. 42, fig. 1, 1918.

[23] Idem, p. 320, pl. 89, fig. 2.

[24] U. S. Geol. Survey Sixth Ann. Rept., p. 558, 1886; U. S. Geol. Survey Bull. 37, p. 43, 1887.

[25] U. S. Geol. Survey Bull. 163, p. 42, 1900.

The probable presence of this species in the Laramie near Erie, Colo., is attested by the single example here figured. It is very fragmentary, lacking nearly all of the basal portion, and the secondaries and ribs are at a more acute angle in the type specimen, but otherwise it appears to be referable to this species.

Occurrence: Laramie formation, Reliance mine, 1¾ miles northeast of Erie, Colo., collected by F. H. Knowlton and G. C. Martin, 1908.

Family LEGUMINOSAE.

Leguminosites? coloradensis Knowlton, n. sp.

Plate XIX, figure 9.

Leguminosites? coloradensis Knowlton [nomen nudum]. U. S. Geol. Survey Bull. 696, p. 352, 1919.

Fruit of large size, flattened obovoid, point of attachment small (apex not seen), thickened or ridged along one side, body provided with numerous fine transverse lines.

This specimen, the only one observed, lacks the apical (?) end but otherwise is apparently perfect. Its present length is 2.5 centimeters, but when perfect it was probably not less than 3 centimeters in length. The width is 1.5 centimeters, and the thickness in its present flattened condition is about 5 millimeters. The transverse lines are obscure, and there is no indication of lines in the other direction.

The generic reference of this specimen is somewhat uncertain, from the fact that it is not perfect and also because it does not lie in the matrix so as to be displayed to the best advantage. In its shape and the transverse lines it somewhat resembles what has been called *Nyssa? racemosa* Knowlton, from the Denver beds at Golden, but it differs greatly in size and in the absence of longitudinal lines or ribs. It may possibly belong to the genus *Podogonium*, so many species of which from the Swiss Miocene are described by Heer,[26] but it is not clear that it is a pod of this character, and, moreover, there are no transverse striae in the forms shown by Heer. In general shape and in size it suggests *Leguminosites? arachioides* Lesquereux,[27] though it differs markedly in the striations and their direction.

Occurrence: Laramie formation, wooded bluff south of Marshall, Colo., collected by A. C. Peale, 1908.

Leguminosites columbianus Knowlton, n. sp.

Plate XIX, figures 4, 5.

Leguminosites columbianus Knowlton [nomen nudum], U. S. Geol. Survey Bull. 696, p. 352, 1919.

As interpreted this appears to have been a small turgid pod which was a little longer than broad, acuminate at the apex, and short-pediceled.

This remarkable form is represented by three specimens, all of which are figured. The two more nearly perfect examples appear to be small pods that have been split along one of the sutures and are now open on the stone. The larger one has a length of 9 millimeters exclusive of the pedicel, which is 2 millimeters long, and a width of 6 millimeters as it is spread open, or 3 millimeters to each "valve." The smaller specimen is 5.5 millimeters long and 6 millimeters wide and is without a pedicel. The third specimen is somewhat crushed and distorted. It is 11 millimeters long and appears to have been 6 or 7 millimeters wide; it also is without a pedicel.

Just at the point of the more crushed specimen there are two small round or oblong, pealike seeds, each 3 millimeters in diameter. Very close to the large perfect specimen is the impression of what appears to have been a similar "seed." There is of course no proof that either of the "seeds" came from these pods, but their proximity renders it possible, if not probable, although none of the pods appear to show traces or imprints of the seeds, as it would seem they should.

It is with hesitation that this fossil is given so definite a name as *Leguminosites*. This genus was instituted for the reception of certain miscellaneous plant remains which appear to belong to the Leguminosae but about which knowledge is too indefinite to permit a satisfactory generic reference. The fossils under consideration appear to belong to the Leguminosae—that is, they appear to be pods from which small round, pealike "seeds" may have escaped. They have a form very like that of certain living species of *Astragalus*, as *A. canadensis* Linné and *A. confertifolius* Gray, or rather, as these would appear when opened and lying in a rock. The identification is to be regarded as tentative, but whatever their nature, they are very definite organisms and undoubtedly may be easily recognized in future.

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[26] Heer, Oswald, Flora tertiaria Helvetiae, vol. 3, pl. 136, 1859.

[27] Lesquereux, Leo, The Tertiary flora: U. S. Geol. Survey Terr. Rept., vol. 7, pl. 59, fig. 14, 1878.

Occurrence: Laramie formation, Erie, Colo.

Leguminosites? laramiensis Knowlton, n. sp.

Plate XVII, figure 4.

Leguminosites? laramiensis Knowlton [nomen nudum], U. S. Geol. Survey Bull. 696, p. 353, 1919.

Leaflet narrowly obovate-lanceolate, broadest well above the middle, whence it narrows evenly in wedge-shaped form to the base and more abruptly to the more obtusely acuminate apex; margin entire; midrib relatively very thick; secondaries thin, obscure, apparently about eight pairs.

This is a small leaf or leaflet 3 centimeters long and about 1 centimeter wide. It is preserved on a rather coarse grained sandstone, which has retained but little trace of the nervation. It is so poorly characterized that the generic reference is very uncertain, hence it is not worth while to institute comparisons with described species, as they might be very misleading.

Occurrence: Laramie formation, opposite sand-lime brick works about 4 miles north of Colorado Springs, Colo., collected by A. C. Peale and G. I. Finlay, 1908, on same stone with *Dombeyopsis trivialis*.

Mimosites marshallanus Knowlton, n. sp.

Plate XVI, figure 4.

Mimosites marshallanus Knowlton [nomen nudum], U. S. Geol. Survey Bull. 696, p. 387, 1919.

Leaflet small, narrowly obovate, very obtusely pointed at the apex and wedge-shaped at the base, 2.75 centimeters long, 14 millimeters wide; margin perfectly entire; nervation faint, consisting of a slender midrib and apparently two or three pairs of secondary branches.

This little leaflet is the only one observed. It is perfect so far as outline goes, but the nervation is obscure. It appears to have been sessile, as the base is slightly enlarged.

Occurrence: Laramie formation, Marshall, Colo., railroad cut between old and new stations, collected by A. C. Peale, 1908.

Cassia? laramiensis Knowlton, n. sp.

Plate XIX, figure 3.

Cassia? laramiensis Knowlton [nomen nudum], U. S. Geol. Survey Bull. 696, p. 146, 1919.

Leaflet small, about 3 centimeters long and 1.3 centimeters wide, ovate or elliptical-lanceolate, rather abruptly rounded at the base, obtusely pointed at the apex; margin apparently entire; nervation rather obscure, consisting of a rather strong midrib and seven or eight pairs of thin, alternate or subopposite camptodrome secondaries.

This little leaf or leaflet is so obscurely preserved that it is hardly worth a name and description. It lacks most of the margin, and this fact of course obscures its affinity. It is referred provisionally to the genus *Cassia*.

Occurrence: Laramie formation, Marshall, Colo., collected by A. C. Peale, 1908.

Cercis eocenica Lesquereux.

Cercis eocenica Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1872, p. 384, 1873.

Lesquereux's description and remarks concerning this species are as follows:

> Leaf nearly round, entire, of a thin texture, smooth surface, deeply cordate at base, nervation of *Cercis canadensis*.
>
> The leaf has its point destroyed; it is apparently obtuse or rounded. Except that it is more deeply cordate than the average leaves of our *Cercis canadensis*, there is no difference whatever between the fossil leaves and those of the living species.

So far as known this species was not again referred to by Lesquereux, and it should probably be omitted from further consideration, yet it is described so definitely that apparently it could be recognized if it should be found, and for this reason it is retained.

Occurrence: Laramie formation, Erie, Colo.

Order SAPINDALES.

Family CELASTRACEAE.

Celastrinites alatus Knowlton, n. sp.

Plate XXV, figures 4, 5; Plate XXVI, figure 1.

Celastrinites alatus Knowlton [nomen nudum], U. S. Geol. Survey Bull. 696, p. 152, 1919.

Leaves thin, membranaceous, ovate or broadly ovate, extended above into a short, sharp acumen and below into a rounded or slightly wedge-shaped base, which is extended down the petiole, producing a decided wing;

margin from or a little below the middle provided with numerous fine, sharp upward-pointing teeth; midrib strong, straight; secondaries about five pairs, opposite or sometimes alternate, emerging at an angle of about 45°, curving a little upward and joining below the margin, thence giving rise to a series of loops which appear to have branches entering the teeth; nervilles strong, at right angles to the secondaries, percurrent.

This species appears to be one of the best-characterized forms belonging to the Laramie. The matrix is a rather coarse sandstone upon which the finer nervation is not well preserved, yet the outline and more characteristic nervation are well shown. It is represented by four specimens, of which the two figured ones are the best. The larger (Pl. XXV, fig. 4) is 5.5 centimeters long and 4 centimeters broad, and the smaller (Pl. XXV, fig. 5) is 6 centimeters long and about 3 centimeters broad. The species is especially characterized by the winged petiole, unequal base, fine teeth above the middle of the blade, and brachidiodrome nervation.

In nervation this species is very similar to *Celastrus cassinefolius* Unger,[28] but the size and shape are very different.

Occurrence: Laramie formation, Murphy's coal bank, Ralston County, north of Golden, Colo.; Erie, Colo., collected by N. L. Britton, 1885.

Celastrinites eriensis Knowlton, n. sp.

Plate XXVI, figure 2.

Celastrinites eriensis Knowlton [nomen nudum], U. S. Geol. Survey Bull. 696, p. 152, 1919.

Leaves small, membranaceous, broadly oval, tapering from the broadest point at the middle regularly to an acute apex and to a similar base which extends as a narrow wing to the petiole; margin finely and sharply serrate; nervation consisting of a thin midrib and four or five pairs of camptodrome secondaries; remaining nervation obsolete.

This species is founded on the example figured, which is 3.5 centimeters long and 1.7 centimeters broad, with the petiole about 1 centimeter long. The nervation is obscure, about the only thing that can be made out being the midrib and the four or five pairs of alternate, thin secondaries which emerge at an acute angle and arch just inside the borders.

This species is found associated with and may possibly belong to *C. alatus*, described above. They both have the same serrate margin and winged petiole and approximately the same nervation, but they differ markedly in shape and size, the leaves of *C. alatus* being several times the size of those of *C. eriensis* and broadly oblong instead of broadly lanceolate.

Occurrence: Laramie formation, Erie, Colo., collected by N. L. Britton about 1884.

Celastrinites cowanensis Knowlton, n. sp.

Plate XVI, figure 6.

Celastrinites cowanensis Knowlton [nomen nudum], U. S. Geol. Survey Bull. 696, p. 152, 1919.

Leaf apparently of rather thin texture, elliptical, probably about 10 centimeters in length and a little less than 5 centimeters in width; upper portion rather abruptly rounded to a short, obtuse point (basal portion destroyed); margin strongly toothed, the teeth rather sharp; midrib very slender; secondaries about seven pairs, alternate, thin, at an angle of 30° to 40°, not much curved upward, disappearing before they reach the margin; none of the finer nervation preserved.

Occurrence: Laramie formation, Cowan station, 10 miles south of Denver, Colo., collected by F. H. Knowlton.

Family ACERACEAE.

Negundo brittoni Knowlton, n. sp.

Plate XXVI, figures 8-10.

Negundo brittoni Knowlton [nomen nudum], U. S. Geol. Survey Bull. 696, p. 405, 1919.

Leaves compound, trifoliate; terminal leaflet largest, long-petioled, broadly ovate, rounded at the base, obscurely three-lobed, the lateral lobes very short, obtuse, apex apparently obtusely acuminate; lateral leaflets short-petioled, oblong, entire, slightly inequilateral; terminal leaflet three-nerved from a point a little above the base, other nerves remote, opposite, effaced at the borders; lateral leaflets with about five pairs of alternate secondaries, which are effaced at their extremities; finer nervation obsolete.

This well-marked species, which I take pleasure in naming in honor of its collector, Dr. N. L. Britton, of the New York Botanical

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[28] Flora tertiaria Helvetiae, vol. 3, p. 67, pl. 121, figs. 25, 26.

Garden, is based upon the several examples figured. In the larger specimen (fig. 10) the whole leaf is about 12 centimeters long, including the petiole, which is 3.5 centimeters long. The terminal leaflet appears to have had a petiole fully 2 centimeters long, and the blade is about 6 centimeters long and 5 centimeters broad. The lateral leaflets have petioles only about 4 millimeters long. The one wholly preserved is 5 centimeters long and 3 centimeters broad. The nervation is obscure, and it is possible to make out only a few of the secondaries.

The genus *Negundo* [29]—if it is to be maintained as distinct from *Acer*—is represented by three living species, with a number of more or less well-marked varieties, and is entirely North American in distribution.

Up to the present time about eight fossil species of *Negundo* have been described, of which three are European and the remainder American. Of these the oldest is *Negundo* (or *Negundoides*) *acutifolia* (Lesquereux) Pax,[30] from the Dakota sandstone of Kansas and Nebraska, which differs in having thin lanceolate leaflets, obscure as to their point of attachment. The next younger species is *N. decurrens* Lesquereux,[31] from the Denver formation at Golden, Colo. This species rests upon a single specimen which has not been figured, but it is regarded by Lesquereux as being closely allied to *N. triloba* Newberry,[32] a species found only in the Fort Union near the mouth of Yellowstone River in Montana. *Negundo triloba* is evidently closely related to the living box elder (*N. aceroides*) and differs from *N. brittoni*, the one here described, in having the terminal leaflet smallest and in all being coarsely toothed.

The only other American species, from the Mascall formation of the John Day Basin, Oreg., was described under the name *Rulac crataegifolium* Knowlton [33] when it was thought that *Rulac* was the tenable name for replacing *Negundo*. This species also rests on a single rather fragmentary specimen and, if correctly interpreted, has the terminal leaflet much smaller than the lateral ones; both are sharply toothed.

The European forms are *N. bohemicum* Menzel,[34] from the Oligocene of Sulloditz, Bohemia, and *N. europaeum* Heer [35] and *N. trifoliata* (Al. Braun) Al. Braun,[36] from the Miocene of Oeningen, neither of which aproaches closely our species.

In North America we have the following species, which, when arranged in ascending geologic order, exhibit what we now know of the development of the genus:

Negundo acutifolia (Lesquereux) Pax	Dakota sandstone.
Negundo brittoni Knowlton, n. sp.	Laramie formation.
Negundo decurrens Lesquereux	Denver formation.
Negundo triloba Newberry	Fort Union formation.
Negundo crataegifolia (Knowlton) Knowlton, n. comb.	Miocene.
Negundo aceroides Moench	Living.

Occurrence: Laramie formation, Marshall, Colo.

Family SAPINDACEAE.

Pistacia eriensis Knowlton, n. sp.

Plate XXVIII, figures 1–4.

Pistacia eriensis Knowlton [nomen nudum], U. S. Geol. Survey Bull. 696, p. 460, 1919.

Leaf compound, imparipinnate, tri(?)-foliolate; rachis slender; leaflets arising from the same point, the terminal one short-petioled, the lateral ones sessile; leaflets oblong-lanceolate, acuminate at the apex, the terminal one with a wedge-shaped base, the lateral ones inequilateral in the upper side, all entire; midrib of leaflets rather strong; secondaries numerous, 14 to 20 pairs, mainly opposite or subopposite, emerging at a low angle, camptodrome; often forking at about one-third their length from the margin, curving just inside the margin and each joining the one next above; additional shorter secondaries frequently interspersed between the principal ones, thence running one-third or sometimes more than half the distance to the margin, becoming obsolete or curving downward and each uniting with the secondary next below; nervilles strong, percurrent, sometimes crossing at right angles to the secondaries, but oftener oblique to them; finer nervation mostly obsolete.

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[29] There has been much discussion as to the propriety of maintaining *Negundo* as a separate genus, and it is probable that the grounds for so doing are inadequate from the botanist's point of view. The box elders appear to be most closely related to the red maples, with which they agree in having the flowers appearing before the leaves, and these two types are separated from other maples by having compound instead of lobed leaves. If the possession of compound leaves was confined to this group (*Negundo*) it might be best to consider them generically separate from *Acer*, but there is another, otherwise unrelated group of Chinese and Japanese species with ternate leaves. For paleontologic purposes it has been thought best to retain the box elders under *Negundo*, though recognizing full well the fact that the basis for this action is not very secure.

[30] Pax, F., in Engler's Bot. Jahrb., vol. 6, p. 356, 1885. Lesquereux, Leo, The Cretaceous flora; U. S. Geol. Survey Terr. Rept., vol. 6, p. 97, pl. 21, fig. 5, 1874.

[31] Lesquereux, Leo, Harvard Coll. Mus. Comp. Zoology Bull., vol. 16. p. 54, 1888.

[32] Newberry, J. S., U. S. Geol. Survey Mon. 35, p. 115, pl. 31, fig. 5, 1898.

[33] Knowlton, F. H., U. S. Geol. Survey Bull. 204, p. 77, pl. 16, fig. 7, 1902.

[34] Naturw. Gesell. Isis, Bautzen, Sitzungsb. und Abh., 1896–97, p. 52, pl. 2, figs. 8–9.

[35] Heer, Oswald, Flora tertiaria Helvetiae, vol. 3, p. 60, pl. 118, figs. 20–22, 1869.

[36] Bruckmann, Dr., Ver. vaterl. Naturkunde Württemberg Jahresb., VI. Jahrg., p. 235, 1850.

This species is represented by the examples showing the compound nature of the leaves and by ten or more detached leaflets. The largest specimen with the leaflets attached has a rachis 3.5 centimeters long, and the terminal leaflet has a petiole about 6 millimeters long. All the leaflets in this specimen are broken, but they must have been at least 5 centimeters long and about 2.5 centimeters wide. In the smaller specimen in which the leaflets are attached only about 5 millimeters of the rachis is preserved, and the petiole of the terminal leaflet is only about 2 millimeters long. These leaflets are much narrower than those in the other specimen, the terminal one being long, narrowly wedge-shaped at the base, and the lateral ones very much narrowed on the upper side. They must, however, belong to the same species as the larger one.

The numerous detached leaflets all appear to have been lateral ones, as they are strongly inequilateral. Several of them are hardly to be distinguished from the lateral leaflets in the larger specimen mentioned above.

Pistacia eriense is obviously related to and possibly identical with *P. hollicki*, described below. They come from the same locality and have many points in common, the principal difference being that the leaves of *P. eriense* are odd-pinnate and those of *P. hollicki* abruptly pinnate. This character, however, does not hold in the living species, as pointed out in the description of *P. hollicki*, but I have decided to keep them separate, provisionally, even on the slight grounds mentioned. There are also minor differences in size and nervation.

Occurrence: Laramie formation, Erie, Colo.

Pistacia hollicki Knowlton, n. sp.

Plate XXVIII, figures 5, 6.

Pistacia hollicki Knowlton [nomen nudum], U. S. Geol. Survey Bull. 696, p. 460, 1919.

Leaves compound, abruptly pinnate; rachis slender; leaflets nearly sessile, oblong-lanceolate, entire, inequilateral on the upper side, slightly rounded or wedge-shaped at the base, abruptly acuminate at the apex; midrib of leaflets strong, secondaries numerous, 10 to 12 pairs, alternate, emerging at a low angle, craspedodrome, frequently forking near the margin, which they enter; tertiaries usually midway between the secondaries, slender, running halfway to the margin and disappearing or bending downward and each joining the secondary next below; nervilles rather strong, percurrent, running obliquely between the secondaries; finer nervation not retained.

This beautiful species is represented by three specimens and seven or eight leaflets, all well preserved. The larger example has the rachis preserved for 2.5 centimeters. The terminal leaflets are sessile and exactly opposite. They are very inequilateral, the upper side near the base being reduced quite to the midrib. They appear to have been about 3.5 centimeters long and are about 1.5 centimeters wide in the broadest part, which is above the middle. The lateral leaflet is 7 millimeters below the terminal ones and has a petiole scarcely 1 millimeter long. It is more nearly oblong-lanceolate and is 3.5 centimeters long and 13 millimeters wide. Like the terminal ones, it is inequilateral, but not to the same extent.

The other example figured has three leaflets preserved, but the point of their attachment can not be made out. They are shorter than those of other specimens, being only 3 centimeters long. They have the same nervation as the others.

It is with considerable certainty that these leaves are referred to the genus *Pistacia*, for in the manner of arrangement and shape of leaflets and nervation they approach closely certain living species of the genus. In the abruptly pinnate character of the leaves, as well as in the shape of the leaflets, they are similar to *P. lentiscus* Linné, a species of southern Europe. They approach more closely, however, some of the abruptly pinnate leaves of *P. mutica* Frick and Meyer, also from southern Europe. Most of the leaves of *P. mutica* are odd-pinnate, at least on the specimen preserved in the herbarium of the United States National Museum, yet now and then one is found which is abruptly pinnate. They have the same shape and arrangement as observed in the fossil. The nervation is also strikingly like that of the fossil species.

I have not been able to see the only American species of the genus—*P. mexicana* Humboldt, Bonpland, and Kunth, of Mexico and possibly southern Texas, but it is described as having a winged petiole and must differ considerably from the fossil under consideration.

A number of fossil species of *Pistacia* have been described, all of which differ more or less from *P. hollicki*. Thus, *P. bohemica* Ettingshausen,[37] from Bilin, has much the same shape but is twice as large and differs in nervation. Certain of the detached leaflets of *P. miocenica* Saporta,[38] from the "Bassin de Marseille," are very much like the lateral leaflets of *P. hollicki*, though broader and somewhat less inequilateral. The other described fossil species approach the living *P. lentiscus* Linné or *P. terebinthinus* Linné.

I have ventured to name this species in honor of Dr. Arthur Hollick, in partial recognition of his kindness in placing this material at my disposal.

Occurrence: Laramie formation, Erie, Colo., collected by N. L. Britton about 1885.

Family ILICACEAE.

Ilex laramiensis Knowlton, n. sp.

Plate XXIV, figures 4–7.

Ilex laramiensis Knowlton [nomen nudum], U. S. Geol. Survey Bull. 696, p. 326, 1919.

Leaves coriaceous, oval, rounded at the base, acute at the apex, the margin provided with scattered, upward-pointing, spiny teeth; midrib rather slender; secondaries four or five pairs, alternate, open, camptodrome, arching some distance inside the margin and each joining the one next above, with branches from the outside entering the teeth; nervilles obscure but apparently percurrent.

These well-characterized leaves are broadly oval, 3.5 centimeters long and about 2 to 2.5 centimeters wide. The margin is remotely spiny-toothed above the lower third of the blade, the teeth pointing upward and separated by rounded sinuses. The camptodrome secondaries have outside branches entering the teeth, a well-known character of the genus *Ilex*.

There can be little or no question of the correctness of referring these leaves to *Ilex*. Among the several living species they undoubtedly approach most closely *I. opaca* Aiton, the well-known holly of the eastern United States. This living species differs in having the spiny teeth outward-pointing and in having more numerous secondaries. The camptodrome arrangement of the secondaries with the branches entering the teeth is very like the arrangement in the fossil under consideration.

Among fossil forms the present one has some resemblance to *Ilex quercifolia* Lesquereux,[39] from Florissant, Colo., which, however, differs in being obovate, with irregular teeth and more numerous secondaries, which enter the teeth directly.

Occurrence: Laramie formation, Erie, Colo., collected by N. L. Britton about 1885.

Order RHAMNALES.

Family RHAMNACEAE.

Ceanothus eriensis Knowlton, n. sp.

Plate XXVI, figures 3–6.

Ceanothus eriensis Knowlton [nomen nudum], U. S. Geol. Survey Bull. 696, p. 151, 1919.

Leaves evidently thick and coriaceous, elliptical or broadly oval, rather abruptly rounded to the base and in about equal degree to the obtuse or abruptly acuminate apex; margin entire for lower third, then finely serrate; nervation craspedodrome, consisting of a strong, straight midrib and three or four pairs of strong, opposite or subopposite secondaries, the lower pair nearly as strong as the midrib and arising at or very near the base of the blade, each of the lower secondaries with three or four rather remote, occasionally forking branches on the lower side; the lower pair of secondaries, which arise at an angle of about 45°, pass upward for a little more than half the length of the blade and end in the margin, as do all the branches; upper pairs of secondaries dividing the blade into two or three approximately equal divisions, arising at a slightly more acute angle than the lower pair and terminating in the margin, the lower pair with one or two branches on the lower side; nervilles rather faint, percurrent, and at right angles to the midrib.

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[37] Die fossile Flora des Tertiärbeckens von Bilin: K. Akad. Wiss. Wien Denkschr., vol. 29, p. 49, pl. 50, fig. 25, 1869.

[38] Annales sci. nat., 5th ser., Botanique, vol. 9, p. 184, pl. 6, figs. 4–6, 1868.

[39] Lesquereux, Leo, The Cretaceous and Tertiary floras: U. S. Geol. Survey Terr. Rept., vol. 8, p. 186, pl. 38, figs. 2–5, 1883.

This species is represented by eight or ten more or less perfect examples, four of which have been figured. They range, so far as can be made out, from 4.5 to about 5.5 centimeters in length and from 3 to 4 centimeters in width. They are elliptical or broadly oval, with a rounded base and an apex which is similarly rounded to an abruptly acuminate point. Each specimen has three or four pairs of secondaries, the lowest of nearly the same size as the midrib and emerging at the top of the petiole and bearing three or four branches on the lower side, while the other secondaries are remote and simple or once or twice branched. The margin is finely serrate from a point one-third or more above the base.

There is considerable uncertainty as to the proper generic reference for these little leaves. They have, for example, the same size, shape, and superficial appearance as *Ficus planicostata* Lesquereux,[40] but they differ at once in the serrate margin and craspedodrome instead of camptodrome nervation. The broader forms have also some resemblance to *Cissus lobato-crenata* Lesquereux,[41] but that species differs in having an irregularly toothed margin and a different, looser nervation. *Morus italica* Massalongo,[42] from the Italian Tertiary, is very suggestive of this species but differs in being five instead of three ribbed from the base and in minor details of nervation. At one time it was thought that these specimens should be referred to *Viburnum*, as certain of the more rounded forms have the shape and much the nervation of *V. dichotomum* Lesquereux,[43] but that species differs in having more prominent teeth and a markedly flexuose midrib. Several of the broader forms approach *V. lakesii* Lesquereux [44] in the configuration of the base, but that species differs in being three-lobed and in having a different branching of the lower secondaries. Among living species of *Viburnum* this much resembles *V. dilatatum* Thunberg, from Japan, which has the shape and dentition but differs in having eight or more pairs of secondaries. From *V. dentatum* Linné it is also distinguished by much the same characters.

But, all things considered, it seems best to refer this form to *Ceanothus*, as it is, for instance, very similar to certain of the rounder-leaved forms of the living *C. americanus* Linné, and more especially to a form presumed to be a hybrid of this, known as *C. azureus*, cultivated in the parks at Washington, D. C. All the fossil leaves, however, appear to be more nearly elliptical than either of the above-mentioned forms. The marginal teeth are similar to those in the living species except that they do not occur on the lower third of the blade. This species differs from *C. azureus* in its larger size, more rounded form, serrate margin, and craspedodrome nervation.

Occurrence: Laramie formation, Erie, Colo., collected by N. L. Britton about 1885.

Ceanothus ovatifolius Knowlton, n. sp.

Plate XXV, figure 3.

Ceanothus ovatifolius Knowlton [nomen nudum], U. S. Geol. Survey Bull. 696, p. 151, 1919.

Leaf cuneate-ovate, 3 centimeters long, 1.5 centimeters wide, long wedge-shaped at the base, rather abruptly acuminate at the apex; margin entire; nervation camptodrome, of about five pairs of opposite or subopposite secondaries, the lower pair arising from the very base just at the margin of the blade, thence running up for nearly two-thirds the length of the leaf and there joining the third pair of secondaries, which in turn arch to the pair next above, the whole forming a line just inside the border; finer nervation not preserved.

This leaf, which is the only one found in the collection, is referred with considerable certainty to the genus *Ceanothus*, being in shape quite like the living *C. ovatus* Desfontaines or *C. velutinus* Hooker and in nervation strikingly like certain of the leaves of *C. americana* Linné. In *C. americana* the lowest pair of secondaries arises at the extreme lower limit of the blade outside the parenchyma, and as they are of the same strength as the midrib the leaf appears triple-nerved. In the fossil leaf the lowest pair of secondaries arises in the same manner, but they are not quite so strong as the midrib, thus producing less of the triple-nerved appearance. This lower pair does not seem to be branched on the outside, as in the living *C. americana*, but the leaf is preserved on a coarse-grained sandstone; none of the finer nervation can be made out. The first pair of prominent secondaries above the base is about in the middle of the leaf.

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[40] Lesquereux, Leo, The Tertiary flora: U. S. Geol. Survey Terr. Rept.. vol. 7, pl. 31, figs. 3, 4, 5, etc., 1878.

[41] Idem, pl. 41, fig. 3.

[42] Synopsis florae fossilus senogalliensis, pls. 10-11, fig. 10, 1859.

[43] Lesquereux, Leo, The Tertiary flora: U. S. Geol. Survey Terr. Rept., vol. 7, pl. 88, fig. 6, 1878.

[44] Idem, pl. 87, fig. 13, 1878.

Occurrence: Laramie formation, Mount Carbon, Morrison, Colo., sandstone near coal seam, collected by Arthur Lakes, June, 1890.

Rhamnus goldianus? Lesquereux.

Plate XVIII, figure 3.

Rhamnus goldianus Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1872, p. 381, 1873; idem for 1873, p. 405, 1874; idem for 1876, p. 517, 1878; Tertiary flora: U. S. Geol. Survey Terr. Rept., vol. 7, p. 281, pl. 53, figs. 4–8, 1878.

The collection from the wooded bluff just south of the station at Marshall, Colo., contains the single fragmentary specimen here figured. It seems to be identical with some of the smaller leaves referred to *Rhamnus goldianus*, but the base and all the sides, except a minute portion, are lacking, and the identification can not be positive. It is a Denver species and has not before been reported from the Laramie.

Occurrence: Laramie formation, Marshall, Colo., wooded bluff just south of station and the highest point in the section, collected by A. C. Peale. Denver formation, Golden, Colo.

Rhamnus salicifolius Lesquereux.

Plate XV, figure 4; Plate XIX, figure 2b.

Rhamnus salicifolius Lesquereux, Am. Jour. Sci., 2d ser., vol. 46, p. 206, 1868; U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1869 [reprint, 1873], p. 196; idem for 1872, p. 400, 1873; idem for 1873, p. 382, 1874; idem for 1876, p. 517, 1878; Tertiary flora: U. S. Geol. Survey Terr. Rept., vol. 7, p. 282, pl. 53, figs. 9, 10, 1878.

Knowlton, U. S. Geol. Survey Bull. 163, p. 70, 1900.

This species was first named from specimens obtained in the Marshall coal mine, Boulder County, Colo. The type specimen is the original of figure 9, Plate LIII, of the "Tertiary flora" and is No. 446 of the United States National Museum collection, though unfortunately it can not be found at present. There is in its place another specimen with the same number which may have been the counterpart of the one figured, although, as it is very fragmentary, it is impossible to be certain of this. It is exactly like Lesquereux's figure 9 in its characters, at least so far as can be made out, and is preserved in the whitish sandstone characteristic of the locality.

The other figured type ("Tertiary flora," Pl. LIII, fig. 10) is said by Lesquereux to have come from Black Buttes, Wyo., where it was obtained by Meek,[45] but as the United States National Museum catalogue of fossil plants made up by Lesquereux does not record the species from Black Buttes, this is probably an error. As the original type of this figure can not be found among specimens of this species from any other locality, it must be ignored until it is found or is again collected from the locality mentioned.

The United States National Museum catalogue records a specimen from Golden, Colo., which is evidently the one referred to by Lesquereux in the Hayden report for 1872, page 382. It is No. 837a and is preserved on the same stone with *Salix integra* Göppert (No. 837). The matrix is a hard, fine-grained whitish sandstone, not unlike that from Marshall, and undoubtedly belongs to the true Laramie.

A specimen of *Rhammus salicifolius* is also recorded from the roof of a coal mine on Sand Creek, Colo. This example (No. 935) bears the imprint of two leaves which are much larger than the figured specimens, being 11 or 12 centimeters long and 4 or 5 centimeters wide, whereas the largest type as figured is 9.5 centimeters long and only 2 centimeters wide. It is possible that this should be referred to a new species.

The material from Cowan station contains several specimens that appear to belong to this species, especially the one shown in figure 4, Plate XV. This is indistinguishable from the type specimen (Lesquereux's fig. 9), from Marshall.

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[45] U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1872, p. 400, 1873.

There are several other leaves that have the same shape and nervation as those described above but are considerably larger. They are referred to *R. salicifolius*, though they may represent a closely related form.

Occurrence: Laramie formation, Marshall, Boulder County, Colo. (type); Cowan station, 10 miles south of Denver, Colo., collected by F. H. Knowlton; cut on Moffat railroad (Denver & Salt Lake), collected by A. C. Peale, 1908. Dawson arkose, Templeton Gap, 4 miles northeast of Colorado Springs, Colo., collected by A. C. Peale, 1908. Vermejo formation, Canon City field (Rockvale), Colo., collected by George Hadden; 2 miles west of Trinidad, Colo., collected by G. B. Richardson. Mesaverde formation, near Harper Station, Wyo.; near the Van Dyke coal, Rock Springs, Wyo., collected by F. H. Knowlton and T. W. Stanton, 1896.

Rhamnus minutus Knowlton, n. sp.

Plate XVII, figure 2.

Rhamnus minutus Knowlton [nomen nudum], U. S. Geol. Survey Bull. 696, p. 548, 1919.

Leaf very small (2 centimeters long, 6 millimeters wide) but of firm, perhaps coriaceous texture, lanceolate, rather wedge-shaped at the base, and obtusely acuminate at the apex; margin entire but slightly undulate; nervation strong, consisting of a very thick midrib and six pairs of alternate secondaries, which are considerably curved upward and apparently enter the margin; nervilles fairly numerous, unbroken, and approximately at right angles to the secondaries.

The nearly perfect little leaf figured is the only one observed. It appears to be most closely related to *Rhamnus salicifolius* Lesquereux and may, indeed, be only a small leaf of that species. The slightly undulate margin and the nervilles at right angles instead of oblique to the secondaries are apparent differences.

Occurrence: Laramie formation, Erie, Colo.

Rhamnus marshallensis Knowlton, n. sp.

Plate XV, figure 3.

Rhamnus marshallensis Knowlton [nomen nudum], U. S. Geol. Survey Bull. 696, p. 547, 1919.

Leaf small, linear-lanceolate, rounded and obtuse at the base (apex not seen); margin entire; midrib very strong, straight; secondaries numerous, probably about 12 pairs, close, parallel, little curved upward, just reaching the border; nervilles numerous, mainly unbroken, approximately at right angles to the midrib.

The little leaf figured is all that was observed of this form. It was probably about 5 centimeters long and is evenly 1 centimeter wide nearly throughout.

This species appears to be most closely related to *Rhamnus salicifolius* Lesquereux, from which it differs in its smaller size, rounded instead of wedge-shaped base, and more numerous secondaries.

Occurrence: Laramie formation, wooded bluff south of Marshall, Colo., collected by A. C. Peale, 1908.

Rhamnus belmontensis Knowlton and Cockerell.

Rhamnus belmontensis Knowlton and Cockerell, U. S. Geol. Survey Bull. 696, p. 544, 1919.

Rhamnus elegans Newberry, New York Lyc. Nat. Hist. Annals, vol. 9, p. 49, 1868; U. S. Geol. Survey Mon. 35, p. 117, pl. 50, fig. 2, 1989.

This fine species has been well described and figured by Newberry. At the time it was named (1868) it was said to have come from "Miocene sandstone, Belmont, Colo.," a statement which reflects the opinion current at the time that all the coal of the West was of Tertiary age. When it was figured in 1898, however, it was said to be from the "Cretaceous (Laramie group), Belmont, Colo.," a statement which again reflects the opinion of the time. A question arose as to the exact location of "Belmont, Colo." No town of this name could be located on any available map of the State, and it was suggested by Prof. Junius Henderson, of Boulder, Colo., to whom an appeal was made, that it might possibly be a corruption of "Valmont," where the Laramie is present. Quite by accident it was discovered that Belmont was the older name for Marshall, as shown by the following quotation from Hayden's discussion of the region:[46] "In the Boulder Valley the Tertiary coal beds are enormously developed. The Belmont or Marshall's coal and iron mines, on South Boulder Creek * * *." This species has not been detected in any of the recent collections from Marshall or elsewhere in the

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[46] U. S. Geol. and Geog. Survey Terr. Third Ann. Rept. (reprint, 1873), p. 129.

Laramie. It rather closely resembles *Rhamnus? williardi* Knowlton,[47] from the Fox Hills sandstone of the Greeley quadrangle, Colo. That species is a little smaller and not quite so truncate at the base, but in nervation there appears comparatively little difference. The type specimen of *R. belmontensis*, however, which is preserved in the United States National Museum (No. 10958), presents an entirely different aspect. The nervation is very thin and delicate, and the nervilles are made out with much difficulty. Notwithstanding the agreement between the leaves in outline, disposition of nervation, etc., it is impossible to believe that the two could belong to the same species.

Occurrence: Laramie formation, Marshall (formerly Belmont), Colo.

Rhamnus brittoni Knowlton, n. sp.

Plate XV, figure 6; Plate XXIV, figure 8.

Rhamnus brittoni Knowlton [nomen nudum], U. S. Geol. Survey Bull. 696, p. 544, 1919.

Leaves rather stiff and evidently coriaceous, lanceolate, 8 or 10 centimeters long, 3 or 4 centimeters wide, apparently obtusely wedge-shaped at the base, long-pointed and sharply acuminate at the apex, broadest about one-third the length of the blade above the base; margin entire; midrib moderately strong, perfectly straight; secondaries relatively strong, numerous (about 14 pairs), close, parallel, at an angle of about 50°, very little curved upward, ending in the margin; nervilles very numerous, close, parallel, mainly unbroken, oblique to the secondaries.

The nearest relative of this species appears to be *Rhamnus elegans* Newberry[48] (now *R. belmontensis*), from the Laramie at Belmont, now Marshall, Colo., with which it agrees closely in size and shape but differs in the more numerous close, parallel secondaries, which are but little curved upward. The nervilles are much the same in both.

This species is also related to *Rhamnus salicifolius* Lesquereux[49] but is much broader and has more numerous secondaries, which are at a lower angle of divergence with the midrib; the nervilles are about the same in both.

Occurrence: Laramie formation, Erie, Colo., collected by N. L. Britton, in whose honor the species is named.

Rhamnus? pealei Knowlton, n. sp.

Plate XV, figure 7.

Rhamnus? pealei Knowlton [nomen nudum], U. S. Geol. Survey Bull. 696, p. 548, 1919.

Leaf evidently rather thick, ovate-elliptical, unequal sided, base truncate on one side, wedge-shaped on the other, apex obtusely acuminate; margin apparently entire; midrib relatively very thick; secondaries 10 or 12 pairs, alternate, strong, nearly at right angles near the base on one side, others gradually at a more acute angle, camptodrome; nervilles numerous and prominent, mainly broken and oblique to the secondaries.

In the specimen figured nearly all of the margin is lacking, but so far as can be made out it was perfectly entire. This leaf is 7 centimeters long and a little over 3 centimeters broad; it is very regular in size from the unequal-sided base to about the upper fourth of its length, where it narrows to the rather obtusely pointed apex.

Occurrence: Laramie formation, cut on Moffat railroad (Denver & Salt Lake) about 6 or 8 miles north of Golden, Colo., collected by A. C. Peale, for whom it is named.

Rhamnus sp.

Plate XVII, figure 1.

In the material from Popes Bluffs, near Pikeview, Colo., was found the single fragmentary leaf here figured. It was apparently about 4 centimeters long and 2 centimeters wide, with entire margin and a rather abruptly rounded and obtuse apex; the base is destroyed. It has a very thick midrib and at least 10 pairs of light camptodrome secondaries. The most marked feature of this little leaf consists of the nervilles, which are very numerous, mainly forked or broken, and oblique to the secondaries.

This leaf is at once suggestive of either *Rhamnus cleburni* Lesquereux or *Rhamnus goldianus* Lesquereux, both well-known Denver species, but it is smaller than either, though approaching *R. goldianus* most closely. In the nervation, except for size, it is not different from either of these species.

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[47] Knowlton, F. H., The flora of the Fox Hills sandstone: U. S. Geol. Survey Prof. Paper 98, p. 91, pl. 16, figs. 1, 2, pl. 17, figs. 1-4, 1916.

[48] Newberry, J. S., U. S. Geol. Survey Mon. 35, p. 117, pl. 50, fig. 2, 1898.

[49] Lesquereux, Leo, The Tertiary flora: U. S. Geol. Survey Terr. Rept., vol. 7, p. 282, pl. 53, figs. 9, 10, 1878.

Rhamnus cleburni was reported by Lesquereux[50] from the Laramie at the old Franceville mine, near Colorado Springs, but it is not found in the recent collections from that place. The present leaf from Popes Bluffs is hardly one-fourth the size of the ordinary leaves of this species and, moreover, differs in shape, being narrower. The absence of the basal portion makes it impossible to decide whether to assign this leaf to *Rhamnus cleburni* or to *Rhamnus goldianus*, and the most that can be said is that the present specimen is of the same type as these species. Its smaller size and narrower outline suggest that it probably is neither of these species, though obviously allied.

Occurrence: Laramie formation, Popes Bluffs, west of Pikeview, Colo. (sec. 14, T. 13 S., R. 67 W.), collected by A. C. Peale and M. I. Goldman, 1908.

Paliurus zizyphoides Lesquereux?

Paliurus zizyphoides Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1872, p. 397, 1873; Tertiary flora: U. S. Geol. Survey Terr. Rept., vol. 7, p. 274, pl. 51, figs. 1–6, 1878.

This form was established on material from Black Buttes, Wyo., a part of which, at least, is still in the collections of the United States National Museum (cf. No. 416a). In the same connection Lesquereux wrote as follows: "The same species, represented by a smaller leaf, has been found at Erie." The Museum collection does not contain a specimen from Erie, nor has this form been noted in any of the recent collections from that place, and it is consequently questioned as a Laramie species.

Occurrence: Post-Laramie (in my opinion), Black Buttes, Wyo. (types). Laramie formation(?), Erie, Colo.

Zizyphus coloradensis Knowlton, n. sp.

Plate XV, figure 5.

Zizyphus coloradensis Knowlton [nomen nudum], U. S Geol. Survey Bull. 696, p. 660, 1919.

Leaf apparently rather thin in texture, elliptical or slightly ovate-elliptical, obtusely wedge-shaped at the base, apparently about the same shape at the apex; margin entire below, possibly slightly toothed above; five-ribbed, the central or midrib stronger than the others, apparently with two or three secondaries high in the upper part; inner pair of ribs nearly as strong as the midrib, passing up well toward the apex of the blade; lower or outside ribs slender, possibly arising from the basal portion of the inner ribs, not reaching for more than half the length of the blade; all finer nervation effaced.

Only a single specimen of this form has been found, and this has lost much of the apical portion. It was presumably about 6 centimeters long and 2.5 centimeters wide. It is preserved on a very soft sandstone, and not many of the details of nervation can be made out except the ribs.

This species may be only a small, narrow leaf of *Zizyphus hendersoni*, but it appears to be a thinner leaf and is possibly toothed in the upper portion. It has also some resemblance to *Zizyphus cinnamomoides* Lesquereux,[51] from the Green River formation, but the latter is smaller, strongly toothed nearly to the base, and only three-ribbed.

Occurrence: Laramie formation, Popes Bluffs, west of Pikeview, Colo. (sec. 14, T. 13 S., R. 67 W.,) collected by A. C. Peale and M. I. Goldman, 1908.

Zizyphus hendersoni Knowlton, n. sp.

Plate XV, figures 1, 2.

Zizyphus hendersoni Knowlton [nomen nudum], U. S. Geol. Survey Bull. 696, p. 660, 1919.

Leaf evidently firm in texture, ovate or ovate-elliptical, rather abruptly rounded to the slightly wedge-shaped base; apex not well preserved but apparently rather obtuse; margin perfectly entire; petiole stout, at least 1 centimeter long; three-ribbed, or in effect five-ribbed, the petiole splitting into approximately three branches or ribs, and just as they leave the wedge-shaped basal portion of the blade each of the lateral ones gives rise to a strong secondary branch which simulates a rib, the five about equally dividing the area of the blade; middle rib straight, with several secondary branches in the upper part; next pair of ribs about as strong as the midrib, ascending well toward the apex of the blade, each with several secondary branches on the outside; lower or outer pair of ribs slightly more slender than the others, passing up for nearly or quite half the length of the blade, each with five or six secondary branches on the outside which arch forward and disappear just inside the margin; nervilles numerous, strong, mainly unbroken, and at right angles to the ribs or secondaries.

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[50] Lesquereux, Leo, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1873, p. 203, 1874.

[51] Lesquereux, Leo. The Tertiary flora: U. S. Geol. Survey Terr. Rept., vol. 7, p. 277, pl. 52, figs. 7, 8, 1878.

This form is represented by a number of examples, of which the two best preserved are here figured. The specimen that is most nearly perfect in outline is shown in figure 2. It is about 9 centimeters long and 5.5 centimeters wide. The nervation shows only the ribs and some of the secondaries, the nervilles being obscure or effaced. The other specimen (fig. 1) comprises only the base of a leaf of about the same size as the one seen in figure 2, but the nervation is much better preserved. The origin of the outer pair of ribs is very well shown in this specimen—that is, they are seen to arise as branches from the inner pair of ribs, thus being virtually secondaries. Each gives rise to some five or six branches on the outside. The nervilles and their disposition are well shown in the figure.

This fine species most closely resembles *Zizyphus fibrillosus* (Lesquereux) Lesquereux,[52] a species well known in the Denver and Raton formations. From this it differs essentially in having the base distinctly wedge-shaped instead of truncate or heart-shaped. The manner in which the principal ribs arise is the same in both species—that is, they are essentially three-ribbed with the lateral and basal secondaries arising just above the base and by their strength simulating ribs. The nervilles in the present species are similar to those in *Zizyphus fibrillosus* except that they are neither so numerous nor so regular.

I take pleasure in naming this species in honor of Judge Junius Henderson, curator of the museum of the University of Colorado, Boulder, Colo.

Occurrence: Laramie formation, in cut in clay beds about 1½ miles south of Golden, Colo., collected by A. C. Peale, 1908; Cowan station, 10 miles south of Denver, Colo., collected by F. H. Knowlton.

Zizyphus corrugatus Knowlton, n. sp.

Plate XVII, figure 3.

Zizyphus corrugatus Knowlton [nomen nudum], U. S. Geol. Survey Bull. 696, p. 660, 1919.

Leaf apparently rather thick in texture, ovate, with abruptly rounded, truncate or slightly cordate base and obtusely pointed apex; seven-ribbed from the top of the petiole, the midrib strong, straight, with two pairs of alternate secondary branches in the upper part; next pair of ribs at an angle of about 80°, passing to the upper margin, each with three or four secondary branches on the outside; next outer pair of ribs at an angle of about 60°, reaching the margin below the middle of the blade, each with two or three secondary branches on the outside; lower pair of ribs at an angle of about 30°, apparently without secondary branches; nervilles thin, few, usually unbroken.

The leaf figured, which is nearly perfect, is about 8.5 centimeters long and about 5 centimeters wide and is very well characterized. This form is in some ways more closely related to *Zizyphus fibrillosus* Lesquereux [53] than *Zizyphus hendersoni*, the form just described. It differs, however, in being more broadly ovate, in having the ribs nearly or quite straight instead of curved, and above all in the character of the nervilles which is much the same in both and is wholly unlike that of *Zizyphus bfirillosus*.

Occurrence: Laramie formation, Cowan station, 10 miles south of Denver, Colo., collected by F. H. Knowlton.

Zizyphus minutus Knowlton, n. sp.

Plate XVIII, figure 1.

Zizyphus minutus Knowlton [nomen nudum], U. S. Geol. Survey Bull. 696, p. 661, 1919.

Leaf of small size, probably about 3.5 centimeters in length and 8 millimeters in width, apparently coriaceous, linear-lanceolate, narrowly wedge-shaped at the base (apex destroyed); three-ribbed from the extreme base of the blade, the ribs nearly equal in strength, the lateral ones passing well up to the apex; all finer nervation obscure or effaced.

Although this species is based on a single specimen, which lacks all of the apical portion, it is obviously so distinct from anything else in these collections that it merits description. It is very unlike either of the other Laramie forms referred to *Zizyphus*—in fact, it belongs to quite a different section of the genus. It is, however, so well characterized, though it is fragmentary, that there should be no trouble in its subsequent recognition.

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[52] Lesquereux, Leo, The Tertiary flora: U. S. Geol. Survey Terr. Rept., vol. 7, p. 276, pl. 52, figs. 1-6, 1878.

[53] Lesquereux, Leo, The Tertiary flora: U. S. Geol. Survey Terr. Rept., vol. 7, p. 276, pl. 52, figs. 1-6, 1878.

Occurrence: Laramie formation, railroad cut between old and new stations, Marshall, Colo., collected by A. C. Peale, 1908.

Order MALVALES.

Family TILIACEAE?

Apeibopsis? laramiensis Knowlton, n. sp.

Plate VII, figure 4.

Apeibopsis? laramiensis Knowlton [nomen nudum], U. S. Geol. Survey Bull. 696, p. 80, 1919.

Leaf evidently membranaceous, broadly ovate, at least 8 centimeters in length and 5.5 centimeters in width, abruptly rounded and truncate at the base, apex destroyed but apparently obtusely pointed; margin perfectly entire; petiole 3.5 centimeters long, slender; midrib straight, rather strong; secondaries about 15 pairs, mostly opposite or subopposite, thin, at an angle of 20° or 30°, close, parallel, very little curved upward, disappearing just before reaching the margin; finer nervation obsolete.

This species appears to be most closely related to *Apeibopsis? discolor* (Lesquereux) Lesquereux,[54] from Black Buttes, Wyo., but it differs in its more truncate base, thinner nervation, and more numerous secondaries.

The generic reference of both these species is more or less questionable, as Lesquereux pointed out when discussing his species, but they are apparently congeneric and may remain for the present with the question mark to indicate this doubt.

Occurrence: Laramie formation, Leyden Gulch, about 6½ miles north of Golden, Colo., collected by A. C. Peale.

Order UMBELLALES.

Family CORNACEÆ.

Cornus suborbifera Lesquereux.

Plate XIV, figures 2, 2a (type).

Cornus suborbifera Lesquereux, Tertiary flora: U. S. Geol. Survey Terr. Rept., vol. 7, p. 243, pl. 42, figs. 2, 2a, 1878; U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1876, p. 512, 1878. [Lesquereux's figure of the type is here reproduced.]

Cornus orbifera Heer. Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1873, p. 402, 1874; idem for 1876, p. 512, 1878.

The type specimen of this species was found in the United States National Museum collections (No. 353) under the name *Cornus orbifera* Heer, with which it was at first identified. Lesquereux explains, however, in the "Tertiary flora," page 243, that on the advice of Saporta he decided to give it a new name, although he found difficulty in distinguishing it from the European species. The type of *Cornus suborbifera* is very imperfect and hardly admits of close comparison.

This species is apparently related to *Cornus impressa* Lesquereux, from the Denver formation of Golden, Colo., but appears to differ essentially in the secondaries emerging at a much more open angle.

Occurrence: Laramie formation, Golden, Colo., in the white sandstone.

Cornus praeimpressa Knowlton, n. sp.

Plate XIV, figure 5; Plate XIX, figure 2a.

Cornus praeimpressa Knowlton [nomen nudum], U. S. Geol. Survey Bull. 696, p. 195, 1919.

Leaf evidently firm in texture, elliptical, apparently rounded or perhaps truncate at the base and abruptly rounded at the apex to a short obtuse point; length about 8 centimeters and width 5 centimeters; midrib very thick, especially below, perfectly straight; secondaries about 10 pairs, mainly alternate, at an angle of about 50°, slightly curved upward, camptodrome, arching just inside the margin; nervilles numerous, strong, mainly unbroken, at nearly right angles with the secondaries; finer nervation obsolete.

This form is based on the single example from Cowan station here figured. It is very well characterized by its regular elliptical outline, very thick midrib, relatively thin secondaries, and nervilles at nearly right angles to the secondaries.

This species, as its name implies, is most closely related to *Cornus impressa* Lesquereux,[55] the type of which came from Mount Bross, Middle Park, Colo., where it was found in beds believed to be of Denver age. So far as known only two additional examples of *Cornus impressa* have been collected. These are a broken individual from the andesitic beds at Golden, Colo., and the leaf from the ravine opposite St. Luke's Hospital in Denver, which was described by Ward[56] as *Cornus emmonsii.*

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[54] Lesquereux, Leo, The Tertiary flora: U. S. Geol. Survey Terr. Rept., vol. 7, p. 259, pl. 46, figs. 4-7, 1878.

[55] Lesquereux, Leo, The Tertiary flora: U. S. Geol. Survey Terr. Rept., vol. 7, p. 343, pl. 43, fig. 3, 1878.

The other leaf described and figured by Ward[57] under the name *Cornus emmonsii* came from beds known to be of Montana age at Point of Rocks, Wyo. In my "Flora of the Montana formation"[58] this specimen was also referred to *Cornus impressa* on the basis of the figure of it given by Ward, but the specimen itself was not then available. This figure will be seen to agree very closely with that of *Cornus impressa,* though much of the essential part of it has been entirely misinterpreted and incorrectly drawn. The margin throughout and the distal terminations of the secondaries are exceedingly obscure. Several of the secondaries seem to enter the margin, but in one place it is possible to demonstrate with considerable certainty that they are camptodrome and arch just within the margin; hence it is probable that all do this. But the apex is entirely wrong in the figure. The point at which it is there made to curve inward is clearly a break, and it was undoubtedly prolonged for a distance of probably 3 or 4 centimeters beyond the point where it is now made to terminate. This is shown by the undiminished thickness of the midrib at the broken upper margin of the blade, as well as by the upper pairs of secondaries, which do not arch but clearly pass beyond the broken margin. This leaf was undoubtedly ovate-acuminate, instead of elliptical-oblong, and is in all probability a small leaf of what has with some hesitation been called *Cornus studeri.* In any event it can not possibly be the same as *Cornus impressa,* and I doubt whether it should be given specific rank.

Among the specimens from the cut on the Moffat railroad (Denver & Salt Lake) near the Leyden mine is a piece of matrix bearing a small leaf of this species and a broken leaf of *Rhamnus salicifolius.* It is only about 5 centimeters long and 2.5 centimeters wide but does not otherwise differ essentially from the larger example figured.

Occurrence: Laramie formation, Cowan station, 10 miles south of Denver, Colo., collected by F. H. Knowlton; cut on Moffat railroad (Denver & Salt Lake), collected by A. C. Peale, 1908.

Cornus sp.

Plate XIV, figure 4.

Leaf of firm texture, elliptical or perhaps elliptical-obovate; margin entire; nervation pinnate, the midrib strong, straight; secondaries about six or seven pairs, at an angle of about 45°, alternate below, subopposite above, camptodrome, arching just inside the border, the upper ones much curved inward and probably reaching the midrib.

The specimen here figured is the only one obtained, and this is fragmentary, lacking all of the base and one side and the extreme tip. It was about 8 centimeters long and a little over 5 centimeters wide. It is very obtuse and rounded above and was probably abruptly rounded below.

This form is of the same type as *Cornus suborbifera* Lesquereux and *Cornus praeimpressa* Knowlton, just described, but differs in its fewer secondaries at a more acute angle.

Occurrence: Laramie formation, Cowan station, 10 miles south of Denver, Colo., collected by F. H. Knowlton.

Family ARALIACEAE.

Hedera lucens Knowlton, n. sp.

Plate IX, figure 1.

Hedera lucens Knowlton [nomen nudum], U. S. Geol. Survey Bull. 696, p. 315, 1919.

Leaves small, thick, evidently smooth and polished on the upper surface, deltoid-ovate, truncate and square-cut across the base, obtusely acuminate at the apex; margin entire; petiole thin, evidently short; midrib thin, straight; secondaries about five or six pairs, very thin and delicate, camptodrome; finer nervation obsolete.

This fine little species is represented by two leaves preserved side by side on the same piece of matrix. One is absolutely perfect; the other is somewhat fragmentary but shows well the nervation. The perfect example is 3 centimeters long and 2.3 centimeters wide, and, so far as can be made out, the other was of similar dimensions.

Occurrence: Laramie formation, Erie, Colo.

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[56] U. S. Geol. Survey Sixth Ann. Rept., p. 553, pl. 48, fig. 2, 1886; U. S. Geol. Survey Bull. 37, p. 55, pl. 26, fig. 2, 1887

[57] Op. cit. (Sixth Ann. Rept.), pl. 48, fig. 3.

[58] U. S. Geol. Survey Bull. 163, p. 68, 1900.

Order EBENALES.

Family EBENACEAE.

Diospyros berryana Knowlton, n. sp.

Plate XVII, figure 5.

Diospyros berryana Knowlton [nomen nudum], U. S. Geol. Survey Bull. 696, p. 237, 1919.

Leaf apparently of medium thickness, broadly lanceolate, broadest near or just below the middle, whence it tapers gradually to the wedge-shaped base and presumably to an acuminate apex, but this portion of the leaf is destroyed; margin entire; petiole apparently rather slender; midrib slender; secondaries about 10 pairs, mainly alternate, thin, arising at angles of 30° to 45° with the midrib arching and joining well below the margin and with a series of large loops outside; nervilles numerous, relatively strong, very irregular and broken, the finer nervation forming irregular quadrangular areas.

The leaf figured was certainly not less than 10 centimeters and may have been as much as 11 centimeters long. It is a little less than 5 centimeters wide. The petiole, which appears to be rather slender, was at least 1 centimeter long.

In size and shape of leaf, as well as in the essentials of nervation, this form is apparently congeneric with the common persimmon (*Diospyros virginiana*) but differs in specific details. It is also congeneric with a species described as *Diospyros copeana* Lesquereux,[59] from Elko, Nev., but differs in its larger size, more pointed apex, and fewer secondaries.

Occurrence: Laramie formation, 2 miles east of Lafayette, Colo., collected by F. H. Knowlton, 1908.

Order GENTIANALES.

Family OLEACEAE?

Fraxinus? princetoniana Knowlton, n. sp.

Plate XXII, figure 7.

Leaf long, lanceolate, acuminate at the apex (base destroyed); margin entire or slightly undulate in the middle portion, sparsely toothed above; midrib slender, straight; secondaries 10 or 11 pairs, opposite or occasionally subopposite, emerging at an angle of 40° or 45°, curving slightly upward in passing to the border, along which they appear to curve; nervilles percurrent, close, parallel, mainly at right angles to the secondaries; finer nervation obsolete.

This form is represented by the single example figured, which unfortunately is very fragmentary, lacking the base and both margins for half the distance above the base. The apex is also split and more or less distorted, and altogether its status is unsatisfactory. I have looked carefully for some known species to which this can be referred, but as none has been found it is necessarily regarded as new. It by no means certainly belongs to the genus *Fraxinus*, but as it appears to resemble certain forms placed in this genus, it has been provisionally so referred.

This specimen was furnished by Prof. William Libbey, jr., of Princeton University.

Occurrence: Laramie formation(?), Sandstone Ridge, east of South Table Mountain, Golden, Colo.

Family APOCYNACEAE.

Apocynophyllum? taenifolium Knowlton, n. sp.

Plate XVI, figure 2.

Apocynophyllum? taenifolium Knowlton [nomen nudum], U. S. Geol. Survey Bull. 696, p. 81, 1919.

Leaf of firm texture, linear-lanceolate, being about 13 centimeters in length and 2 centimeters in width; it is abruptly rounded to the obtuse base (apex destroyed); petiole very thick, apparently short; margin entire; midrib very thick below but thin above, straight; secondaries few, eight or nine pairs, alternate, thin, regular, emerging at an angle of about 45°, considerably curved upward, camptodrome; finer nervation not retained.

This form, represented only by the fragment shown in the figure, is too imperfect to be regarded as adequately characterized, and consequently the generic reference has been questioned. It was a long, narrow leaf that was rather abruptly rounded at the base and presumably acuminate at the apex. It is not closely similar to any other form found in these beds.

Among the several species of *Apocynophyllum* described from this country may be mentioned *Apocynophyllum sordidum* Lesquereux,[60] from the Dakota sandstone of Kansas. That species, however, is a smaller leaf, is distinctly ovate-lanceolate, and has numerous secondaries. The form here described is of about the same size and shape as *Apocynophyllum wilcoxensis* Berry,[61] from the Raton formation of southern Colorado, but differs in having fewer and more curved secondaries.

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[59] Lesquereux, Leo, The Tertiary flora: U. S. Geol. Survey Terr. Rept., vol. 7, p. 232, pl. 40, fig. 11, 1878.

[60] Lesquereux, Leo, Flora of the Dakota group: U. S. Geol. Survey Mon. 17, p. 109, pl. 64, fig. 11, 1892.

Occurrence: Laramie formation, Leyden Gulch, 6 or 8 miles north of Golden, Colo., collected by A. C. Peale, 1908.

Order POLEMONIALES.

Family BIGNONIACEAE.

Dombeyopsis obtusa Lesquereux.

Plate XIII, figure 4; Plate XX, figure 11; Plate XXVII, figures 1–4.

Dombeyopsis obtusa Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1872, p. 375, 1873; idem for 1873, p. 382, 1874; idem for 1876, p. 514, 1878; Tertiary flora: U. S. Geol. Survey Terr. Rept., vol. 7, p. 255, pl. 47, figs. 4, 5, 1878.

Leaves subcoriaceous, entire, round oval, obtuse, cordate; nervation three-palmate.—Lesquereux.

This species was first described from a specimen found in Gehrung's coal bed, near Colorado Springs, Colo., but the specimen does not appear to belong to the United States National Museum unless, to judge from the description, it is the specimen figured as one of the types,[62] which is recorded in the Museum catalogue as coming from Golden, Colo. It is probable, however, that the original is not now preserved, for the specimen above mentioned agrees in character with others known to be from Golden.

The two figured types are preserved in the United States National Museum (Nos. 380, 381) and if they are correctly labeled, both came from the lower or true Laramie at Golden. The collection also contains another example from the same locality.

There is a single very fine example of this species (No. 281d) from the upper or Denver beds at Golden. It was only partly exposed, but by removal of the matrix the whole of a large and very perfect leaf was revealed. This agrees in shape with *Dombeyopsis obtusa* and in nervation rather more closely with *Dombeyopsis platanoides*, all of which goes to show that these species are very closely allied.

In the material from Coal Creek, Boulder County, Colo., I find three specimens which clearly belong to this species. All are more nearly perfect than Lesquereux's types, and two, shown in Plate XXVII, figures 1, 2, are preserved nearly entire. The smaller of these two specimens lacks only a small portion of the base, and the larger a portion of the side and apex. In figure — the two lateral thick ribs are parallel with the midrib for at least two-thirds of the upper portion, as in Lesquereux's figure 5. The other specimen figured has the base as in his figure 5, while the ribs are slightly more divergent than in his figure 4. The unfigured example is almost the exact counterpart of Lesquereux's figure 4, thus connecting them all with his species.

As stated above, the type of *Dombeyopsis obtusa* appears to have come from the true Laramie near Colorado Springs, Colo., and the finding of these specimens is a satisfactory confirmation of the horizon of which they are characteristic.

The collections made by Lakes at the Douglas coal mine, Sedalia, Colo., embrace three or four rather fragmentary specimens that appear to belong also to this species. They represent only basal portions of the leaves, for it seems to be the unfortunate circumstance that leaves of this type are as a rule poorly preserved. So far as I am able to determine there is no distinction to be drawn between them and the types of *Dombeyopsis obtusa*, and they are so referred.

In figures 3 and 4 of Plate XXVII are shown specimens from Marshall's coal mine, near Golden, Colo., that appear indistinguishable from the leaves from Coal Creek shown in figures 1 and 2, the only difference being the further splitting of the petiole, or rather the origin of the three ribs at a lower point than in the other. As a result of this lower origin of the ribs the basal portion of the lamina is slightly more decurrent, but otherwise in shape and nervation these leaves are certainly identical.

Several fragmentary examples, which are indistinguishable from Lesquereux's figured types are present in the small collection from Crow Creek, Colo.

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[61] Berry, E. W., U. S. Geol. Survey Prof. Paper 91, p. 342, pl. 103, figs. 2, 3; pl. 108, fig. 4, 1916. Knowlton, F. H., U. S. Geol. Survey Prof. Paper 101, p. 345, pl. 103, fig. 3; pl. 105, figs. 1, 2; pl. 106, fig. 1, 1918.

[62] Lesquereux, Leo, op. cit. (Tertiary flora), pl. 47, fig. 4.

Occurrence: Laramie formation, Gehrung's coal mine, near Colorado Springs, Colo. (type); Coal Creek, Colo.; Marshall's coal mine, at Marshall, Colo.; Hoyt's coal mine, 1 mile south of Golden, Colo.; and Crow Creek, 25 miles northeast of Greeley, Colo. Denver formation, 3,000 feet east of Douglas coal mine, Sedalia, Colo. Dawson arkose, Pulpit Rock, near Colorado Springs, Colo.

Dombeyopsis trivialis Lesquereux.

Plate XIII, figure 3; Plate XIV, figure 3.

Dombeyopsis trivialis Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1872, p. 380, 1873; idem for 1873, pp. 382, 404, 1874; idem for 1876, p. 514, 1878; Tertiary flora: U. S. Geol. Survey Terr. Rept., vol. 7, p. 255, pl. 47, fig. 3, 1878. [Lesquereux's original figure is here reproduced as Pl. XIII, fig. 3.]

The type specimen of this species is preserved in the collections of the United States National Museum (No. 379) and is found on the hard white sandstone characteristic of the Laramie at Golden, Colo. The species has not been detected in any of the subsequent collections from this locality, but in the material from a locality north of Colorado Springs there occurs the fragment shown in Plate XIV, figure 3, which appears referable to this species. Although only a fragment of the basal portion of one side, it appears to agree with the type in essential details. It is, for instance, deeply heart-shaped at the base, with several large lobes on the margin. The nervation consists of three principal ribs, with a lighter basal pair which makes it in effect five-ribbed. Branches from lateral strong ribs pass to the marginal lobes, and probably the basal pair of ribs also terminated in more or less pronounced lobes.

Dombeyopsis trivialis is undoubtedly closely related to *D. platanoides* Lesquereux,[63] from which it differs, according to Lesquereux, in being smaller, in having the nervation less deeply marked, with all the nerves thinner and with the secondaries placed in the upper part of the leaf at a great distance above the base. The two lower veinlets coming from the top of the petiole indicate a tendency for the leaf to become five-ribbed. Whether these are characters of sufficient weight to separate these two forms must remain for more complete material to settle.

The present species is also like *Dombeyopsis obtusa* Lesquereux [64] in general shape and nervation but differs in having the margin lobed instead of entire. It is possible that when a sufficient amount of material can be obtained it may show that all three forms are referable to a single species, but for the present they must be kept apart.

Occurrence: Laramie formation; Golden, Colo. (type), collector not known but probably F. V. Hayden; opposite sand-lime brick works about 4 miles north of Colorado Springs, Colo., collected by A. C. Peale and G. I. Finlay, 1908.

Dombeyopsis? sinuata Knowlton, n. sp.

Plate XXV, figures 1, 2.

Dombeyopsis? sinuata Knowlton [nomen nudum], U. S. Geol. Survey Bull. 696, p. 243, 1919.

Leaf evidently thin and membranaceous, apparently broadly ovate, well rounded to a slightly cordate base and probably a rather obtuse apex; margin undulate-sinuate; midrib very thick, especially below, provided above with several pairs of thin, alternate, remote secondaries that fork and send branches to the marginal undulations; just above the base of the blade there is a pair of opposite, strong ribs that arise at an angle of about 45° and pass up for more than half the length of the blade, each with five or six rather strong secondary branches that are at right angles to the midrib and apparently end in the marginal teeth; below the large ribs is a pair of thin ribs that bear thin secondary branches on the lower side; finer nervation can not be satisfactorily made out.

The example shown in figure 1 is in a poor state of preservation, being folded around the rock on which it is imprinted and more or less effaced by rubbing. As nearly as can be made out it is broadly ovate, about 15 centimeters long and nearly 12 centimeters wide. It is in effect five-ribbed; the midrib is very thick and strong, as are a pair of ribs which arise at an angle of 45° some distance above the base and pass up for apparently more than half the length of the blade. Below this pair of strong ribs is a second pair of much more slender ribs which arise at nearly a right angle and are provided with secondary branches on the lower side. The margin of the blade seems to be entire for a short distance above the base, then strongly undulate-sinuate. The nervation all appears to be craspedodrome, ending in the large marginal teeth.

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[63] Lesquereux, Leo, The Tertiary flora: U. S. Geol. Survey Terr. Rept., vol. 7, pl. 47, figs. 1, 2, 1878.

[64] Idem, pl. 47, figs. 5, 6.

The poor state of preservation makes it difficult properly to place this leaf, but on the whole it appears to be most like the several species of *Dombeyopsis* figured by Lesquereux, and I have provisionally referred it to that genus. It is larger than even the largest leaf figured by Lesquereux and differs in being quasi five-ribbed and in having a looser, more forked nervation. It is perhaps closest to *Dombeyopsis platanoides* Lesquereux,[65] from the Bozeman coal field, Mont., but has a much more sinuate-toothed margin and a different nervation.

A specimen has been found among the Coal Creek material which seems to belong with this species. This specimen is much broken but was evidently a leaf of large size. It is more deeply heart-shaped than the first and has an enormously thick midrib and lateral ribs. Except as regards size it has exactly the same character of nervation as the type, including the secondary ribs at right angles to the midrib and below the strong lateral ribs; the nervilles are also the same.

I am in doubt as to the correctness of referring these leaves to *Dombeyopsis*, but they may perhaps remain here until more nearly perfect examples are forthcoming.

Occurrence: Laramie formation, Coal Creek, Boulder County, Colo. (type).

Dombeyopsis ovata Knowlton, n. sp.

Plate XXIV, figures 1–3, 9.

Dombeyopsis ovata Knowlton [nomen nudum], U. S. Geol. Survey Bull. 696, p. 243, 1919.

Leaves rather membranaceous, ovate in general outline, rounded and truncate or very slightly heart-shaped at the base, rounded above into a very small acuminate point; margin entire below, then undulate or provided with two or three low, rounded lobes which are separated by shallow rounded sinuses; triple-nerved from the base of the blade, the central or midrib slightly the stronger, nearly straight, provided above with about six or seven pairs of strong, very irregular, remote, and alternate secondaries, of which the lower one is often forked; the secondaries curving very near the margin and each joining the one next above or running along just inside the margin and fading out; lateral ribs arising at the base of the blade at an angle of about 50°, running nearly straight to the margin, just inside which they apparently curve inward and join the lower pair of secondaries, each with six or eight secondary branches on the lower side which are approximately at right angles to the midrib, somewhat curved upward, often forked, each curving near the margin and forming by union with the next higher one a series of large bows; nervilles thin, percurrent, and broken.

This form is represented in the collection by several well-preserved leaves, four of which are figured. There is considerable range in size, the smallest (fig. 3) being about 6.5 centimeters long and 4 centimeters wide and the largest (fig. 1) about 10 centimeters long and 7 centimeters wide. The leaf shown in figure 9 is 9.5 centimeters long and 6 centimeters wide. The configuration of the base is shown in figures 1 and 2 and is found to be truncate or very slightly heart-shaped.

This species seems to be related to *Dombeyopsis platanoides* Lesquereux,[66] from the Bozeman coal field of Montana. It is, however, much longer and narrower, being ovate instead of nearly circular, and, further, is truncate instead of very deeply heart-shaped at the base. The nervation is similar in character in the two species, except that in *D. ovata* the lateral ribs are at a slightly more acute angle.

Occurrence: Laramie formation, Erie, Colo.

SYSTEMATIC POSITION UNCERTAIN OR UNKNOWN.

Carpites lakesii Knowlton, n. sp.

Plate XIX, figures 6–8.

Carpites lakesii Knowlton [nomen nudum], U. S. Geol. Survey Bull. 696, p. 135, 1919.

Fruit evidently hard-shelled, ovoid, rounded at the base, apparently acuminate at the apex, surface not obviously striate or otherwise marked.

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[65] Lesquereux, Leo, The Tertiary flora: U. S. Geol. Survey Terr. Rept., vol. 7, pl. 47, fig. 2, 1878.

[66] Lesquereux, Leo, The Tertiary flora: U. S. Geol. Survey Terr. Rept., vol. 7, pl. 47, figs. 1, 2, 1878.

The material from the Murphy coal mine, near Golden, Colo., contains several obscure fruits, the best of which are here figured. Fruits of this kind are all unsatisfactory, and I have hesitated to name them, but they undoubtedly represent a type of vegetation present in these beds and should perhaps legitimately be designated for the benefit of future workers, though their affinities are and probably must remain uncertain.

These fruits appear to occur in pairs, though there is no evidence of organic connection, and it may be that this association is merely accidental. The shape and apparent consistence suggest the hard, stony putamen of certain species of *Prunus*, but this is mere conjecture. They are perhaps sufficiently well figured to permit subsequent identification.

Occurrence: Laramie formation, Murphy coal bank, Ralston County, Colo., west of Golden, collected by Arthur Lakes, June, 1890.

Carpites lesquereuxiana Knowlton, n. sp.

Carpites lesquereuxiana Knowlton [nomen nudum], U. S. Geol. Survey Bull. 696, p. 135, 1919.

Fruit large, about 18 millimeters long, about 17 millimeters in greatest diameter and 13 millimeters in least diameter, slightly obovoid, with a broad, flat base and an obtuse apex; provided with about twelve well-defined ridges or ribs at the base and up the sides which by their union are reduced just below the apex to about five.

This specimen is recorded in the fossil-plant catalogue of the United States National Museum (No. 951) as *Carpites rostellatus* Lesquereux—that is, the small piece of matrix on which it occurs is so recorded. The smaller of the two fruits on this matrix obviously belongs to *Carpites rostellatus*, but the one above described is quite different and undoubtedly represents a new species.

Occurrence: Laramie formation, Coal Creek, Boulder County, Colo.

Carpites rhomboidalis Lesquereux.

Carpites rhomboidalis Lesquereux, Tertiary flora: U. S. Geol. Survey Terr. Rept., vol. 7, p. 306, pl. 60, figs. 28, 29, 1878; U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1876, p. 520, 1878.

The two types of this species are on one piece of matrix, which is No. 507 of the United States National Museum collections. They represent so far as known the only specimens obtained.

In the "Tertiary flora," page 306, this species is said to have come from South Table Mountain, near Golden, Colo., but as the matrix is the coarse white sandstone so characteristic of the true Laramie, it is practically certain that the specimen did not come from that locality, where the rock is of Denver age, but from a locality south or west of Golden, where the Laramie is known to be exposed.

Occurrence: Laramie formation, Golden, Colo.

Phyllites leydenianus Knowlton, n. sp.

Plate XVIII, figure 5.

Phyllites leydenianus Knowlton [nomen nudum], U. S. Geol. Survey Bull. 696, p. 446, 1919.

Leaves of thick texture, ovate, somewhat unequal at the base, margin and apex practically destroyed; midrib very strong; secondaries only two or three pairs, the lowest pair arising a short distance above the base and producing a pseudo three-ribbed appearance, each with a few tertiary branches on the outside; next pair of secondaries near the middle of the blade, opposite, strong, apparently craspedodrome, but this can not be made out with certainty.

This form is represented by several leaves, all of which are so fragmentary that the whole character can not be made out. It appears to have been ovate and entire, being about 9 centimeters long and 5 centimeters wide. The only portion of the margin preserved is at the base. The peculiarity of this form lies in the nervation, the two pairs of especially strong secondaries being opposite and probably craspedodrome. The affinities of this leaf are not recognizable, though it can probably be recognized for stratigraphic purposes.

Occurrence: Laramie formation, Leyden Gulch, 6½ miles north of Golden, Colo., collected by A. C. Peale, 1908.

Phyllites marshallensis Knowlton, n. sp.

Plate XXVIII, figure 7.

Phyllites marshallensis Knowlton [nomen nudum], U. S. Geol. Survey Bull. 696, p. 446, 1919.

Leaf large, coriaceous, lanceolate, apparently rounded at the base, narrowly acuminate at the apex; margin prominently undulate, the lobes and sinuses broadly rounded; midrib exceedingly strong below, becoming very thin above; secondaries about 12 pairs, alternate, thin, arising at a low angle, much curved upward, camptodrome, arching near the margin, along which they pass in a series of loops; nervilles numerous, both percurrent and broken; finer nervation forming an intricate network of large and small irregularly quadrangular areolae.

This remarkable leaf is the only one observed in the collections. It is rather broadly lanceolate, about 16 centimeters long, and was undoubtedly several centimeters longer when perfect; the width at the broadest point is about 5.5 centimeters. The margin is deeply undulate, and both lobes and sinuses are broadly rounded. The midrib, as may be seen from the figure, is extremely thick below, where it exceeds a thickness of 3 millimeters, but in the upper portion of the blade it is reduced almost to the vanishing point.

I am entirely at a loss to suggest the proper generic reference for this leaf. The very thick midrib and arching, camptodrome secondaries suggest certain species of *Ficus*, but I do not regard this resemblance as sufficient warrant for placing it under this caption. For the present it may remain as designated.

Occurrence: Laramie formation, Marshall's mine, Boulder County, Colo., collected by N. L. Britton about 1885.

Phyllites trinervis Knowlton, n. sp.

Plate XXIV, figure 12.

Phyllites trinervis Knowlton [nomen nudum], U. S. Geol. Survey Bull. 696, p. 449, 1919.

Leaf evidently thick and leathery, ovate, broadly rounded below to an apparently decurrent base, very obtuse and rounded above; margin perfectly entire; triple-ribbed from the extreme base of the blade, the ribs of equal size, the middle one with about three pairs of alternate, thin, much curved secondaries, the lateral ones with several secondary branches on the outside; all secondaries seemingly camptodrome; finer nervation not retained.

The little leaf here figured is broadly and very obtusely ovate, the length being 5 centimeters and the width about 4 centimeters. The base is broadly rounded, with a slightly decurrent portion through which pass the three ribs, their origin evidently being the top of the petiole. Little of the other nervation is preserved, and this is well shown in the figure.

The real affinities of this leaf are hard to make out. It has, for example, exactly the same type of base, as regards shape, size, and nervation, as *Ficus trinervis*, a part of which was formerly called *Cinnamomum affine* Lesquereux, but the upper portion of the leaf is wholly different.

The basal portion of this leaf is also similar to a form from Marshall that has been described as *Populus distorta* (p. 126), but it differs in having the apex rounded instead of acuminate. In general shape it suggests *Populus arctica* Heer, as figured by Lesquereux,[67] but it differs in details of primary nervation. It also suggests one of the leaves from the Bozeman coal field described under the name *Populus* cf. *P. arctica* Heer,[68] but the Bozeman leaf differs markedly in the primary nervation.

Occurrence: Laramie formation, Coal Creek, Boulder County, Colo.

Phyllites dombeyopsoides Knowlton, n. sp.

Plate XVIII, figure 2.

Phyllites dombeyopsoides Knowlton [nomen nudum], U. S. Geol. Survey Bull. 696, p. 445, 1919.

Leaf ovate, truncate or possibly slightly heart-shaped at the base, regularly and obtusely acuminate at the apex; margin slightly undulate, especially about the middle of the blade; apparently triple ribbed from or near the base of the blade, the central or midrib very much the strongest, especially below, with two pairs of strong, remote secondary branches in the upper part; lateral ribs slender, at an angle of about 60°, with a large lateral branch in the lower portion, this with several tertiary branches on the outside which arch just inside the margin; lateral ribs forked above, the branches passing to or near the margin, the rib itself arching in a broad bow and joining the lower secondary on the midrib; intermediate secondaries and nervilles strong, unbroken.

This form is represented by the leaf figured and several rather poor fragments. The example figured, which lacks both base and apex, is about 14 or 15 centimeters in length and 10 centimeters in width, and the widest point is at about one-third the length of the blade above the base. It is rather broadly ovate and has a distinctly undulate margin. The nervation is remarkable for the very thick midrib, with only two pairs of secondaries in the upper part.

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[67] Lesquereux, Leo, The Tertiary flora: U. S. Geol. Survey Terr. Rept., vol. 7, pl. 23, fig. 5, 1878.

[68] Knowlton, F. H., U. S. Geol. Survey Bull. 105, pl. 6, fig. 7, 1892.

This species appears to be closely related to *Dombeyopsis ovata*, from which, however, it differs in its larger size, more distinctly undulate margin, and fewer secondary branches on the midrib, as well as by the joining of the upper secondaries before they reach the margin. It also resembles certain species of *Ficus* of the *Ficus planicostata* group, yet it apparently differs in essential ways.

Occurrence: Laramie formation, Cowan station, 10 miles south of Denver, Colo., collected by F. H. Knowlton.

Phyllites sp.

Plate XIX, figure 1.

Phyllites sp. Knowlton [nomen], U. S. Geol. Survey Bull. 696, p. 450, 1919.

In the material obtained by Peale in the cut on the Moffat railroad (Denver & Salt Lake) some 6 or 8 miles north of Golden, Colo., is the fragment here figured. It is only the basal portion of what was apparently a large leaf and shows the very thick midrib and the pair of nearly as strong lateral ribs, each of which is branched on the outside. It is doubtful if any portion of the margin is preserved.

This specimen is so fragmentary that there is little use in speculating as to its probable affinity, though it is not unlike certain species of *Platanus*, such as *Platanus raynoldsii*, figured by Lesquereux in the "Tertiary flora," Plate XXVII, figure 1, but obviously it can have little value beyond calling attention to the fact of the presence of a large, perhaps platanoid leaf in these beds.

Occurrence: Laramie formation, cut on Moffat railroad (Denver & Salt Lake) 6 or 8 miles north of Golden, Colo., collected by A. C. Peale, 1908.

Phyllites sp.

Plate XVI, figure 5.

Phyllites sp. Knowlton [nomen], U. S. Geol. Survey Bull. 696, p. 450, 1919.

The fragment of the tip of the small toothed leaf here figured is all that was observed of this form and is hardly worthy of mention except to call attention to the presence of this type of leaf. Its affinity is obviously uncertain. It might be the apical portion of the leaf of a maple (*Acer*) or a sycamore (*Platanus*), but it is quite impossible to decide further.

Occurrence: Laramie formation, Marshall, Colo., collected by A. C. Peale, 1908.

Phyllites sp.

Plate VIII, figure 5.

Phyllites sp. Knowlton [nomen], U. S. Geol. Survey Bull. 696, p. 451, 1919.

In the material from Cowan station, near Denver, is the fragmentary leaf here figured. It was a lanceolate leaf with a wedge-shaped base and presumably an entire margin and was evidently of firm texture. It was 10 centimeters or more long and 3.5 centimeters wide. The nervation is strongly marked, consisting of a strong midrib and probably about six pairs of strong alternate secondaries at an acute angle of divergence. None of the finer nervation is preserved.

This leaf has some resemblance to what has been described as *Ficus cowanensis*, especially to the leaf shown in Plate IX, figure 3, and it is to be noted that they come from the same locality. The latter is a larger leaf and has the secondaries more numerous and at a less acute angle. The fragment under discussion has some suggestion of certain narrow leaves of *Quercus*, but it is too fragmentary to be certain of the reference to that genus. On the whole it seems best to refrain from giving it a definite designation.

Occurrence: Laramie formation, Cowan station, south of Denver, Colo., collected by F. H. Knowlton, 1908.

Palaeoaster? similis Knowlton, n. sp.

Plate XXIV, figures 10, 11.

Palaeoaster? similis Knowlton [nomen nudum], U. S. Geol. Survey Bull. 696, p. 427, 1919.

Organism consisting of a whorl or rosette apparently of about six thick, linear-lanceolate, acuminate, erect, one-nerved "leaves" or segments which are sessile or nearly sessile on a short, stout stem or axis.

This form is represented by the nearly perfect example figured and a number of detached segments. So far as can be made out this species consists of about six "leaves" or segments which are disposed in a whorl at the top of a short, stout branch or axis. The individual "leaves" are narrowed to a long wedge-shaped basal portion and apparently are not in contact with one another. The only nervation that can be observed is a thick midrib.

This species appears to be related to a curious organism from the extreme upper part of the Vermejo formation and the lowermost part of the Raton formation of southern Colorado, described under the name *Palaeoaster inquirenda* Knowlton,[a] as follows:

> It consists of usually about 9 (the number ranges from 8 to 12) narrow, erect "leaves" or members which are 3.5 to about 4.5 centimeters long and 6 to 10 millimeters wide in the middle. They are slightly narrowed to the sessile base, where they are in contact, though evidently perfectly free at the point of attachment. Above they are narrowed to a quite slender acuminate apex, which is usually somewhat incurved. The segments are thick and leathery, if not indeed woody, and are traversed diversely by a deep median furrow. * * * It seems probable that these organisms were terminal, for there is some evidence of the presence of a scar or point of attachment at the base, but there has never been noted any axis on which they might have stood. They are certainly not leaves whorled around a stem, for had they been, some trace of the stem should have been detected in some of the numerous specimens that have passed in review. It appears more likely that they were capsular in nature, for if the now spreading segments were brought together they would apparently make a tightly closed "capsule." The incurved tips of the segments lend support to this view, though no evidence of seeds or any interior structure has been observed.

The specimen under consideration appears to differ in several particulars from those above described. Thus, instead of eight to twelve "leaves" there are apparently only five or six; instead of being in contact at their bases they are slightly separated and have much more the appearance of a whorl of leaves; and finally, instead of being sessile they appear to stand on a short stem or axis. The individual "leaves" or segments are practically indistinguishable in the two forms, and the question naturally arises whether they are slightly different phases of the same or similar organisms, or whether they should be considered wholly distinct. In the absence of sufficient material it is deemed best to describe them as separate species, and I have even questioned the generic reference of the present form.

Occurrence: Laramie formation, Murphy's coal mine, Ralston County, west of Golden, Colo.

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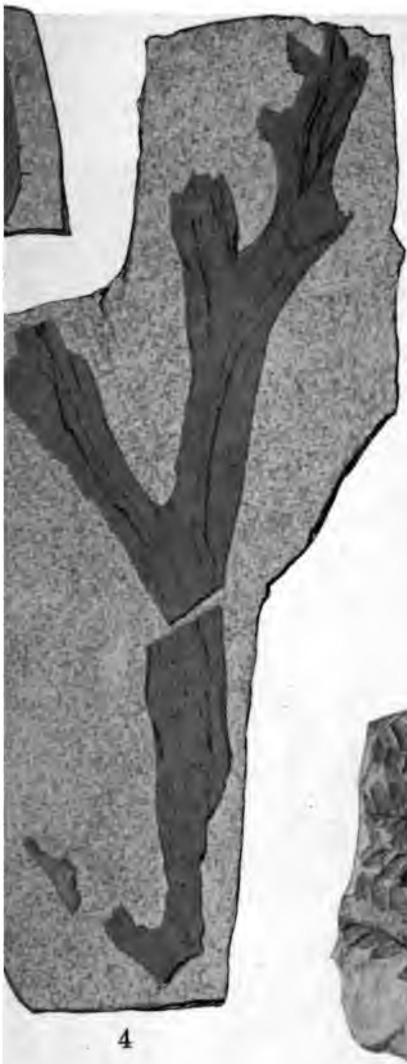
[a] Knowlton, F. H., U. S. Geol. Survey Prof. Paper 101, p. 278, pl. 49, figs. 5, 6, 1918.

PLATES.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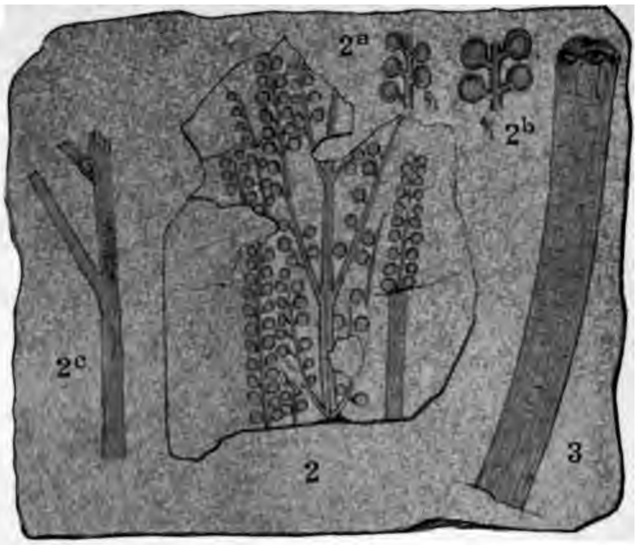

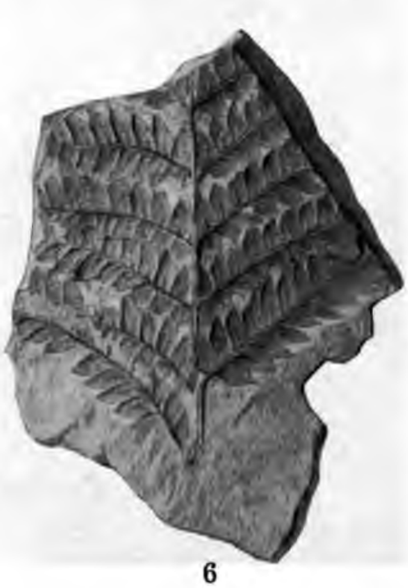
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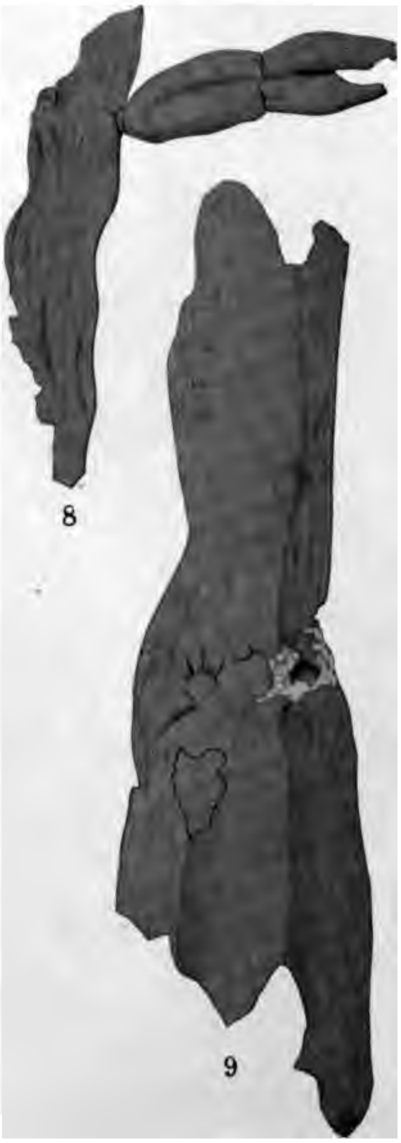

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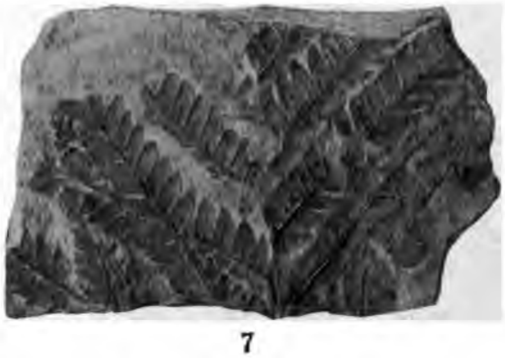
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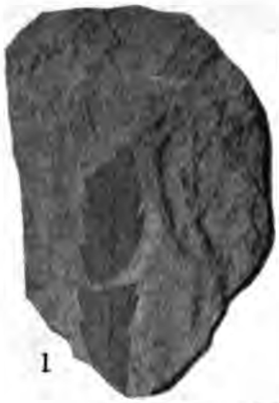
LARAMIE FLORA.

mpactum Lesquereux (reproduced from Lesquereux, Leo;
ora, pl. 5, fig. 9, 1878); p. 113.
unda (Lesquereux) Knowlton (reproduced from Lesquereux,
t., pl. 14, figs. 1-3); p. 107.
Lesquereux (reproduced from Lesquereux, Leo, op. cit.,
)); p. 107.

5. ***Dryopteris laramiensis*** **Knowlton, n. name (reproduced from Lesquereux, Leo, op. cit., pl. 4, fig. 14); p. 109.**
6, 7. ***Dryopteris georgei*** **Knowlton, n. sp.; p. 108.**
8, 9. ***Equisetum perlaevigatum*** **Cockerell (reproduced from Lesquereux, Leo, op. cit., pl. 6, figs. 6, 7); p. 113.**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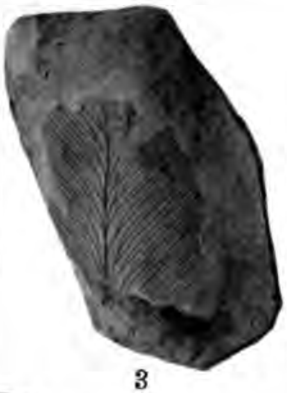
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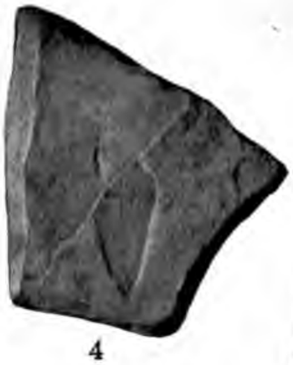
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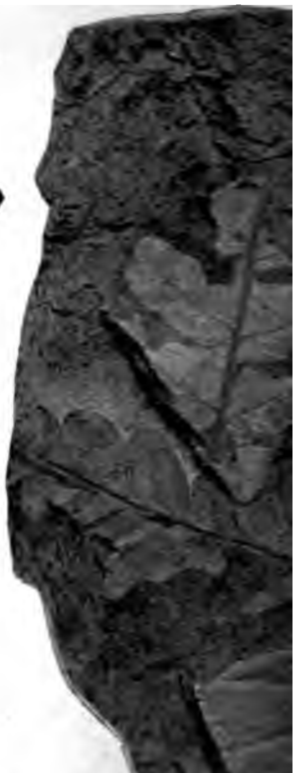
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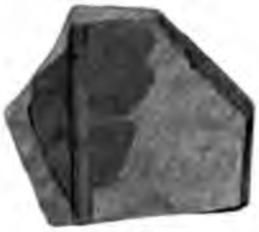
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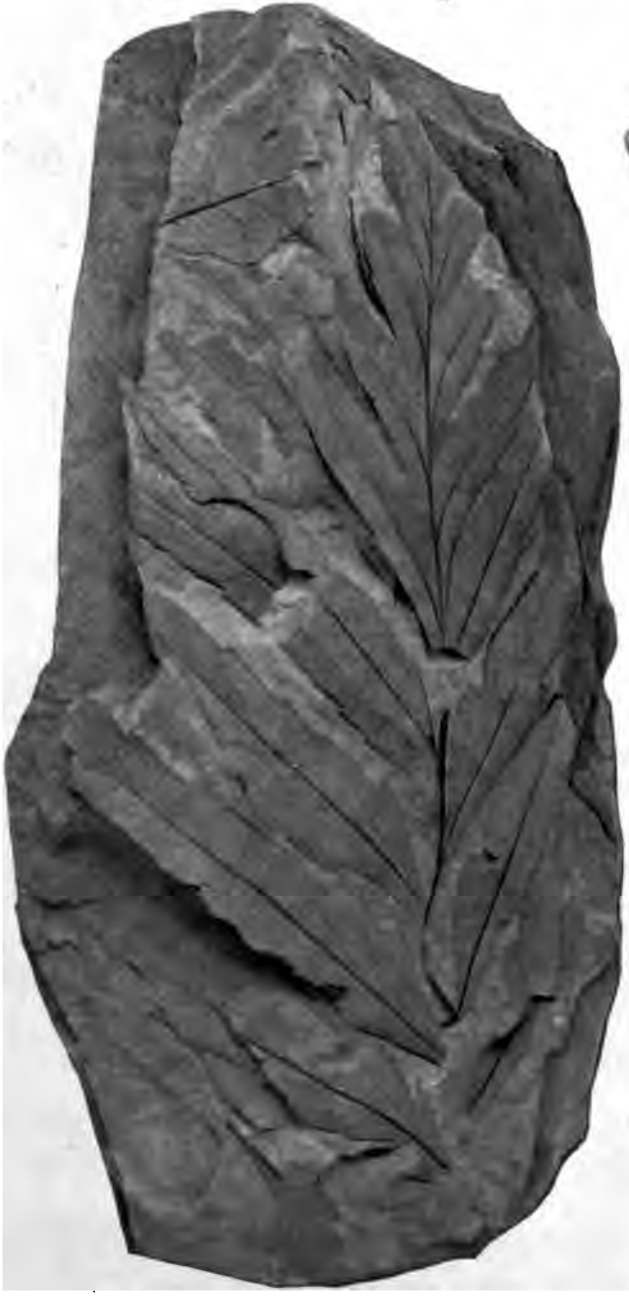
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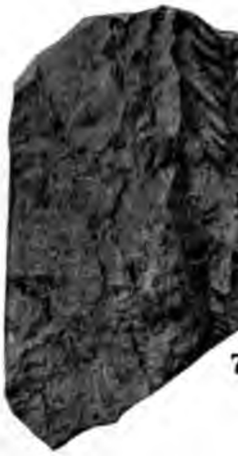
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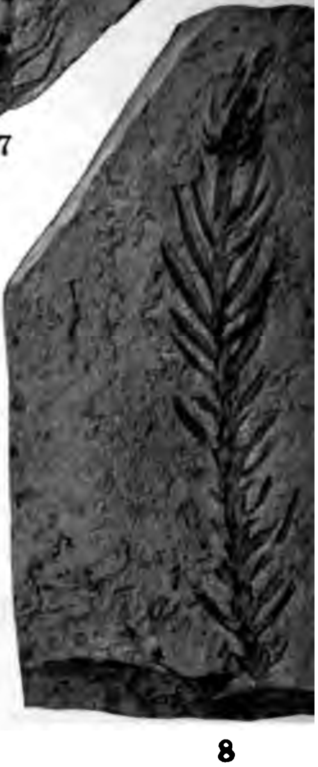
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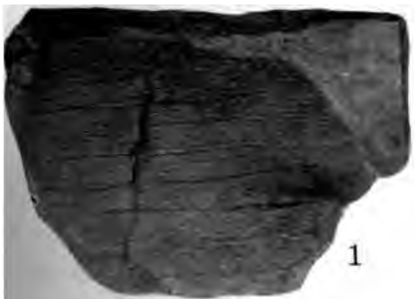
LARAMIE FLORA.

1. *Anemia* sp.; p. 113.
2. *Anemia elongata* (Newberry) Knowlton, n. comb.; p. 112.
3. *Pteris goldmani* Knowlton, n. sp.; p. 111.
4. *Dammara* sp.; p. 114.
5. *Pteris?* sp.; p. 112.
6. *Asplenium martini* Knowlton, n. sp.; p. 111.
7, 8. *Sequoia acuminata?* Lesquereux; p. 114.



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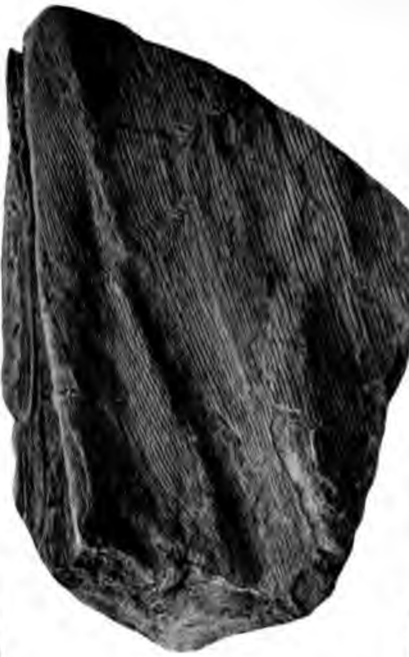

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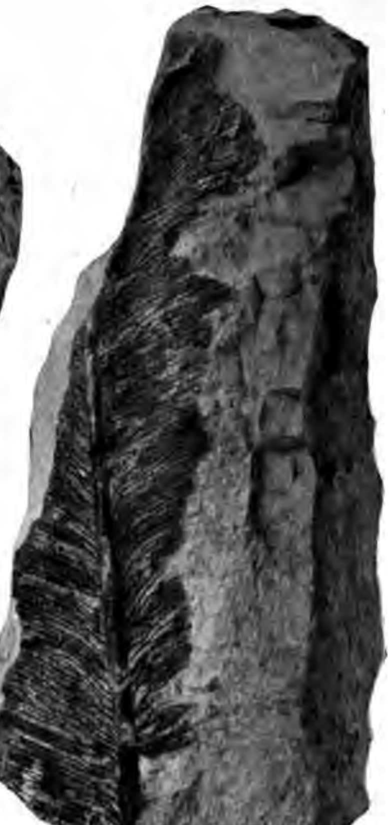

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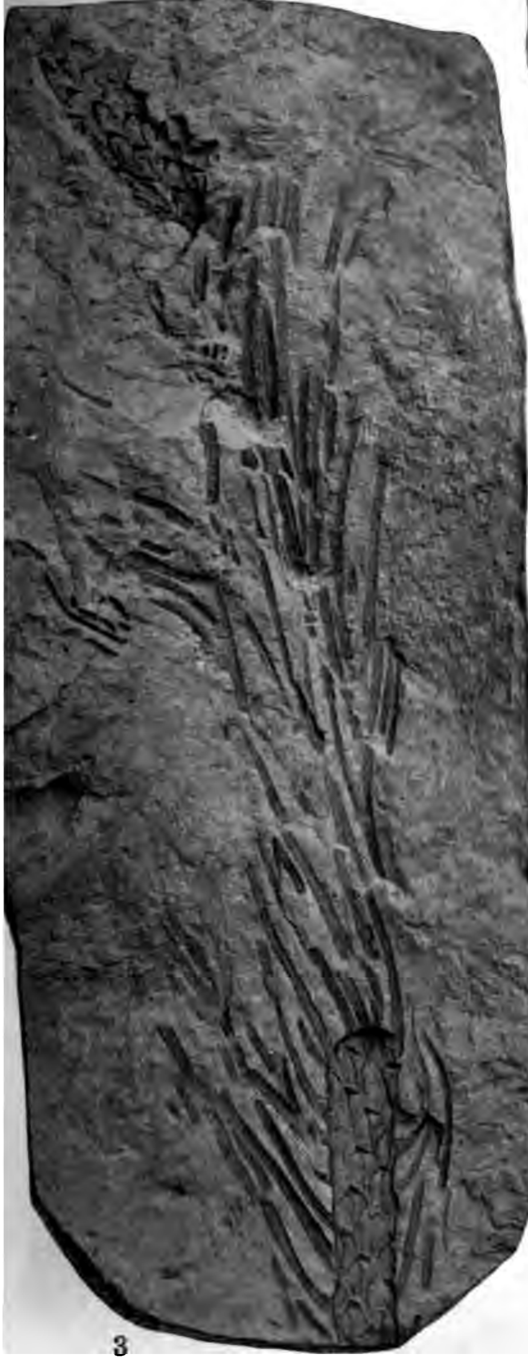

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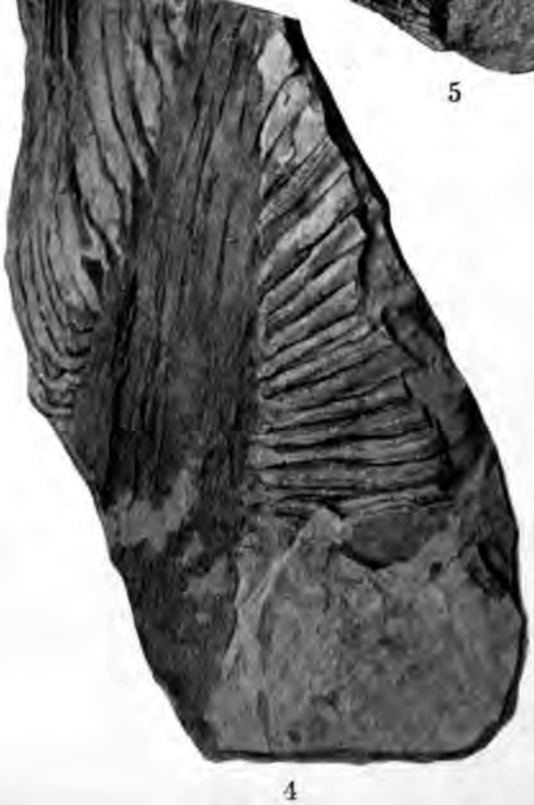

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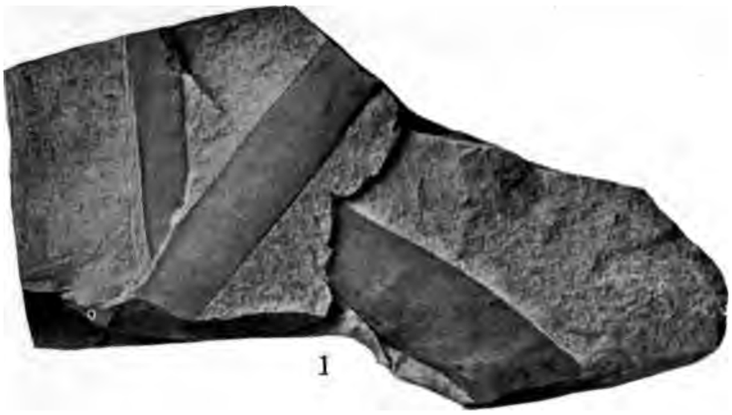
LARAMIE FLORA.

1, 2. *Cyperacites? tessellatus* Knowlton, n. sp.; p. 117.
3. *Sequoia longifolia* Lesquereux; p. 115.
4. *Sabal montana* Knowlton; p. 119.
5. *Phanerophlebites pealei* Knowlton, n. gen., n. sp.; p. 110.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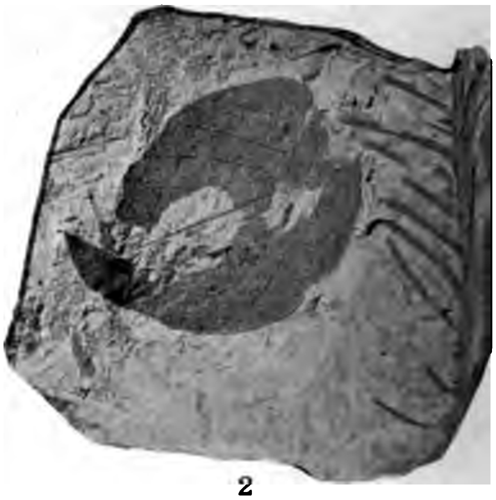
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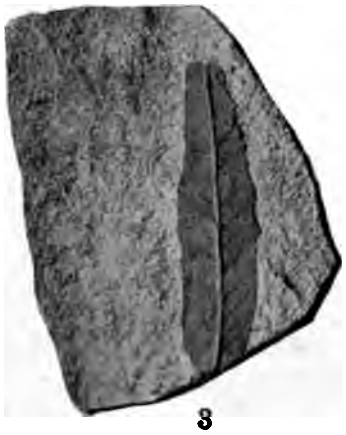
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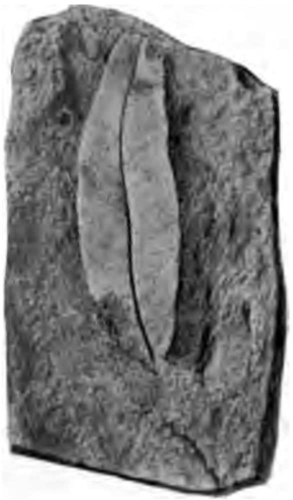
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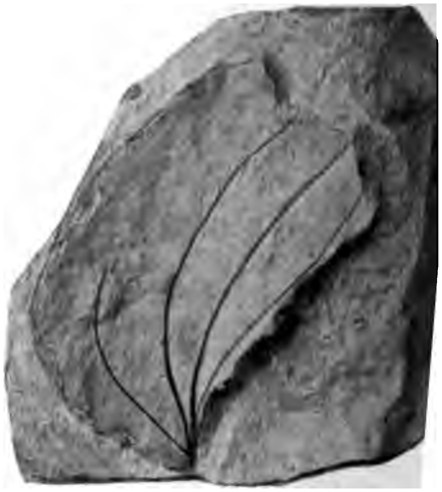
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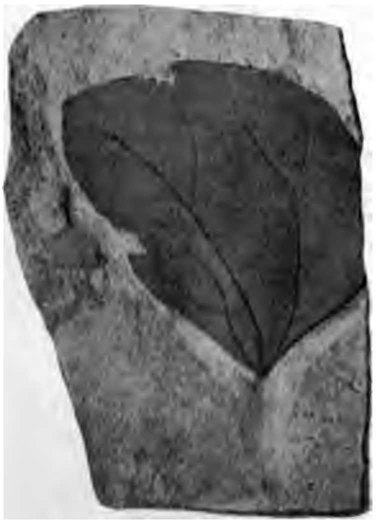
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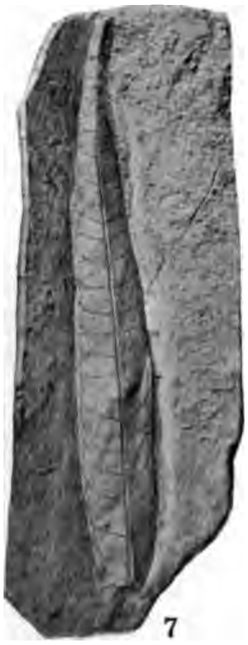
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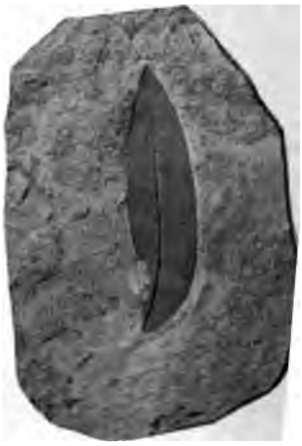
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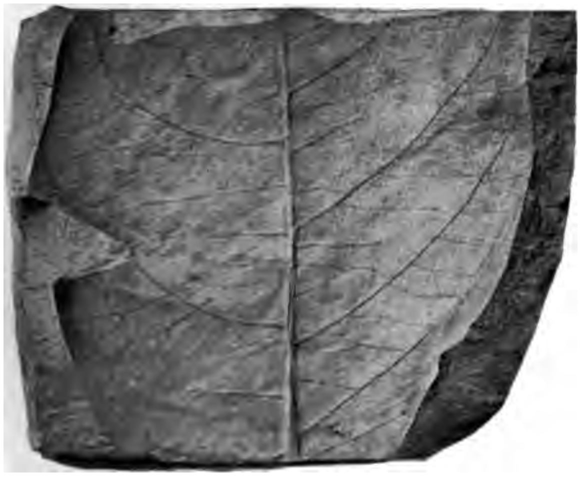
LARAMIE FLORA.

1. *Cyperacites* sp.; p. 117.
2. *Sequoia longifolia?* Lesquereux; p. 115.
3, 4. *Salix wyomingensis* Knowlton and Cockerell; p. 125.
5. *Smilax inquirenda* Knowlton, n. sp.; p. 118.
6. *Populus? distorta* Knowlton, n. sp.; p. 126.
7. *Salix myricoides* Knowlton, n. sp.; p. 124.
8. *Salix wyomingensis?* Knowlton and Cockerell; p. 125.



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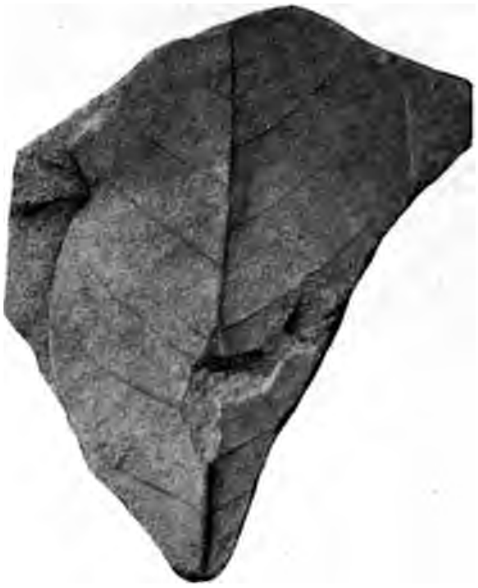

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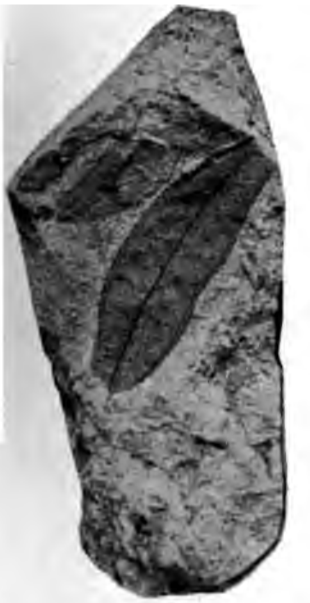

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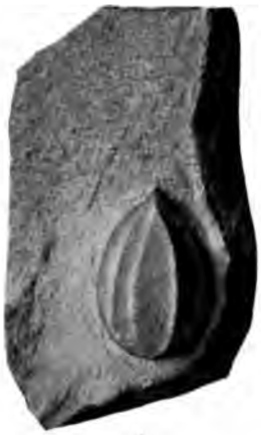

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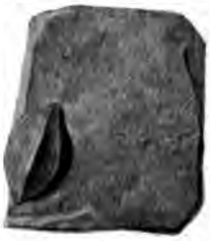

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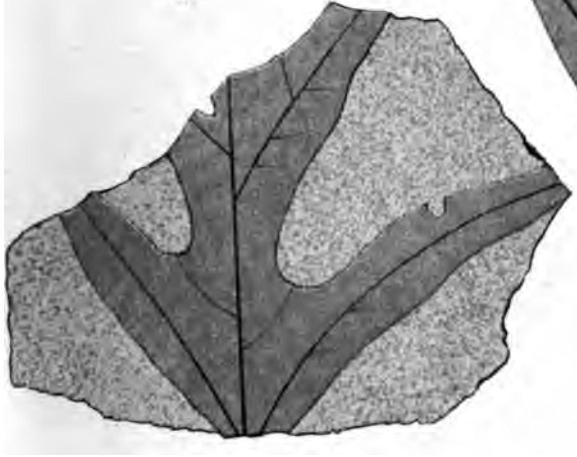

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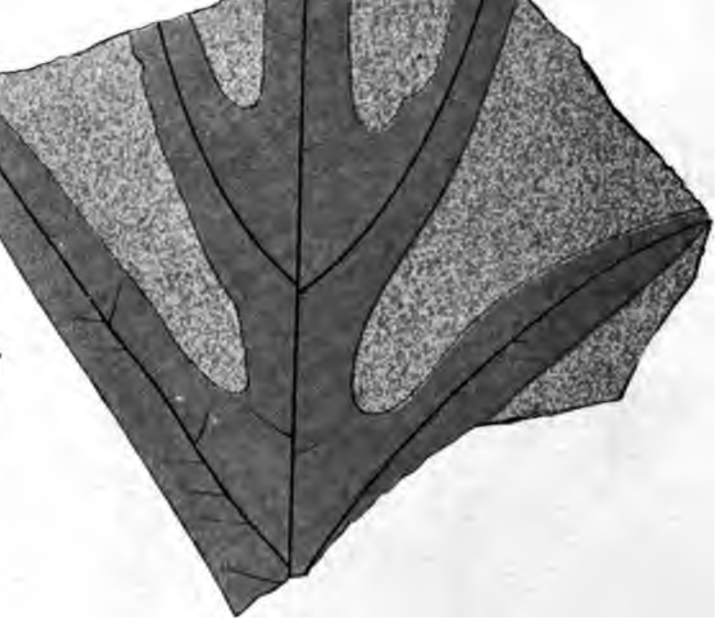

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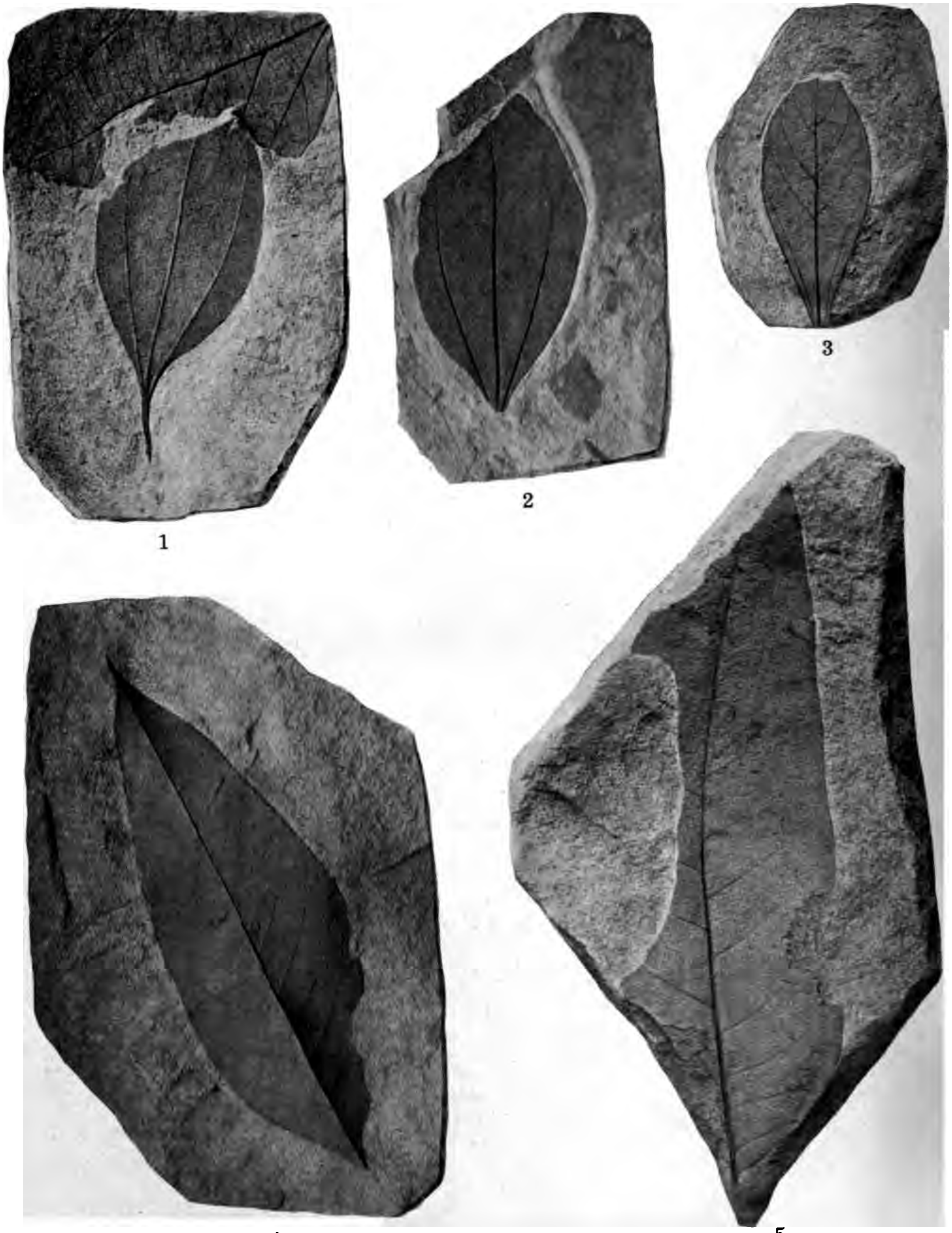
LARAMIE FLORA.

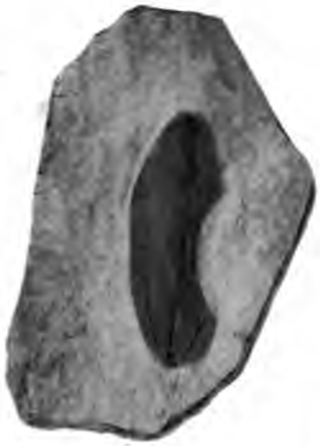
1. *Juglans leydenianus* Knowlton, n. sp.; p. 119.
2. *Juglans praerugosa* Knowlton, n. sp.; p. 121.
3. *Myrica dubia* Knowlton, n. sp.; p. 123.
4. *Hicoria angulata* Knowlton, n. sp.; p. 122.
5. *Hicoria minutula* Knowlton, n. sp.; p. 123.

6, 7. *Quercus praeangustiloba* Knowlton, n. sp. (reproduced from Lesquereux, Leo, Tertiary flora, pl. 21, figs. 4, 5, 1878); p. 126.



LARAMIE FLORA.

1, 2. *Ficus post-trinervis* Knowlton, n. sp.; p. 136.
3. *Ficus cannoni* Knowlton, n. sp.; p. 136.
4, 5. *Ficus navicularis* Cockerell; p. 137.



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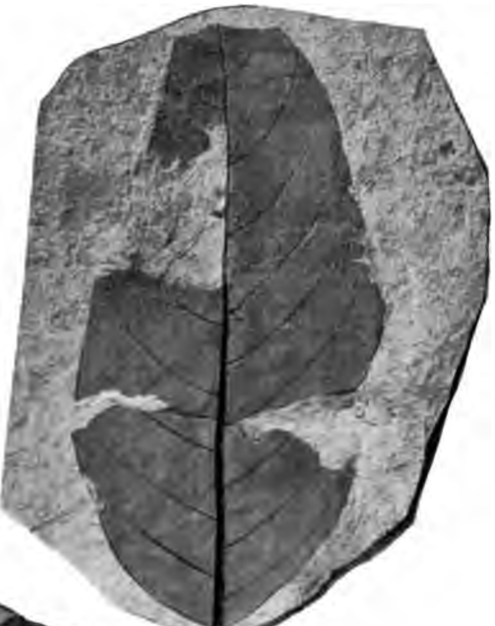

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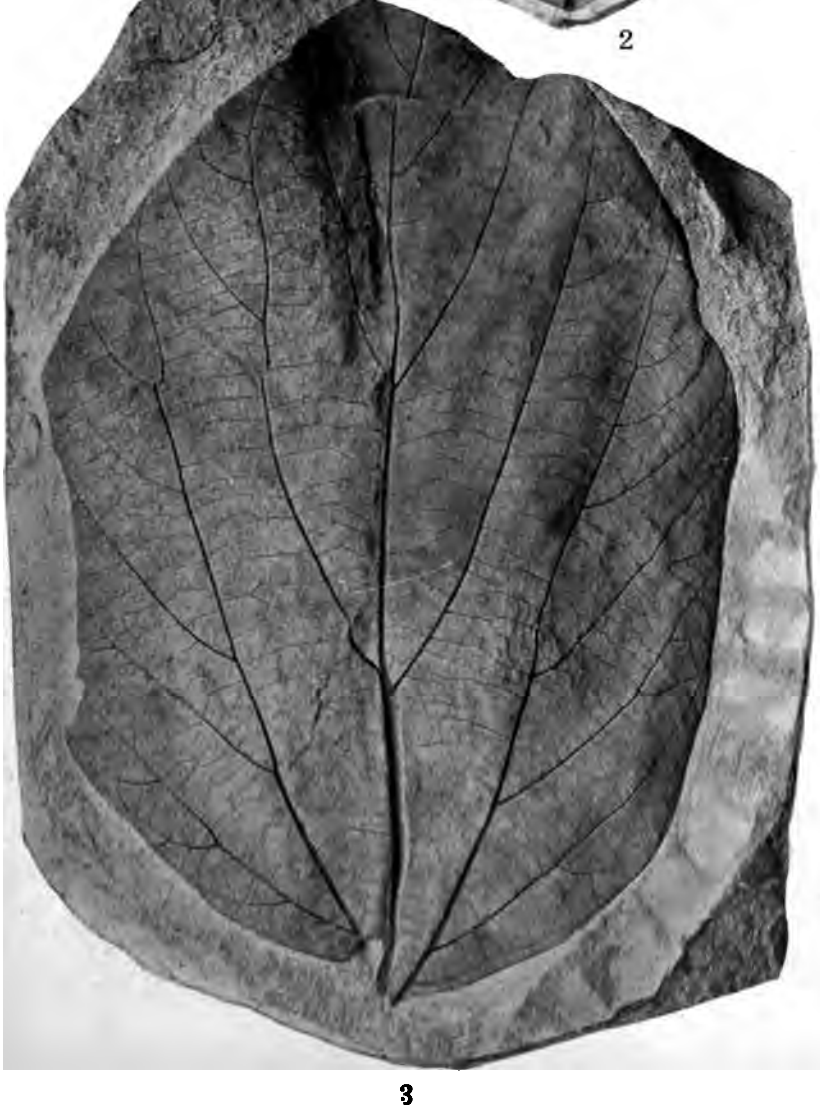

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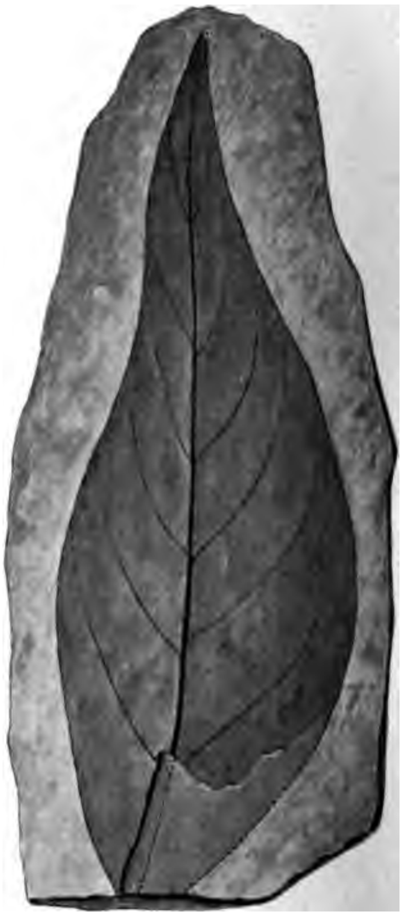

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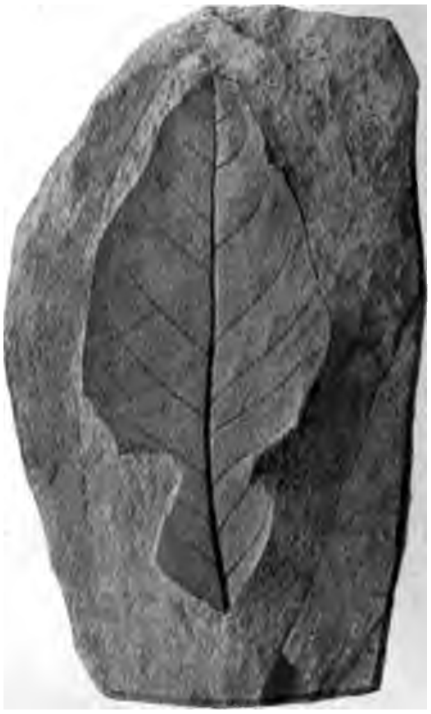

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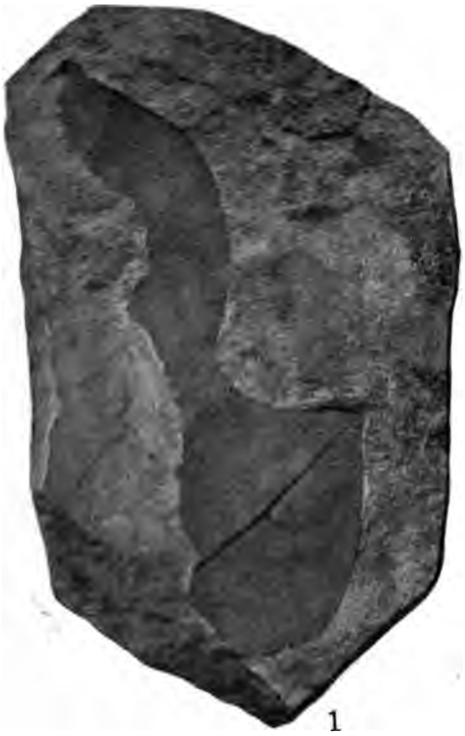
LARAMIE FLORA.

1. *Ficus cannoni* Knowlton, n. sp.; p. 136.
2. *Ficus arenacea* Lesquereux; p. 140.
3. *Ficus planicostata magnifolia* Knowlton, n. var.; p. 133.
4, 5. *Ficus arenacea* Lesquereux; p. 140.



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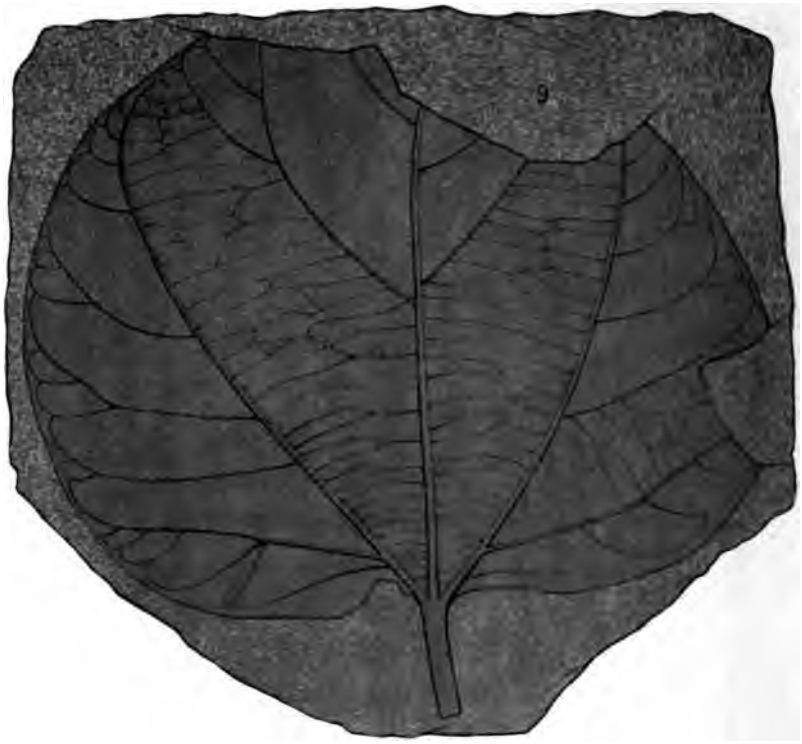

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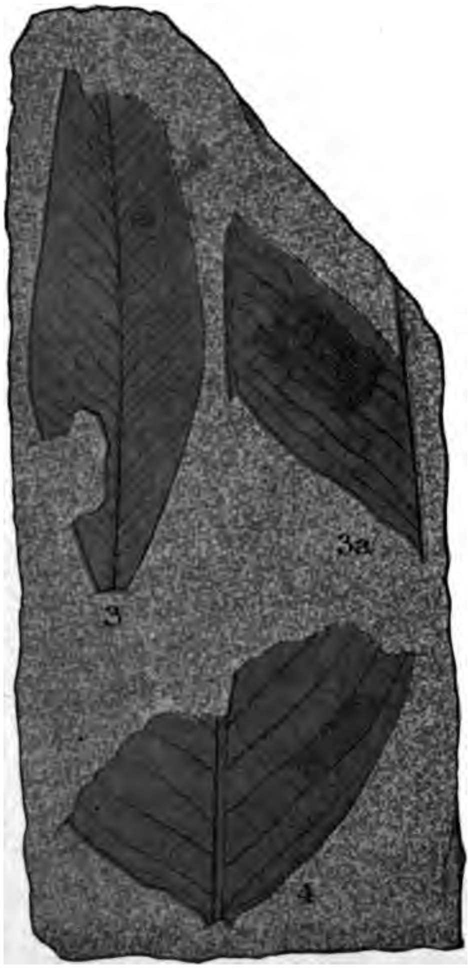

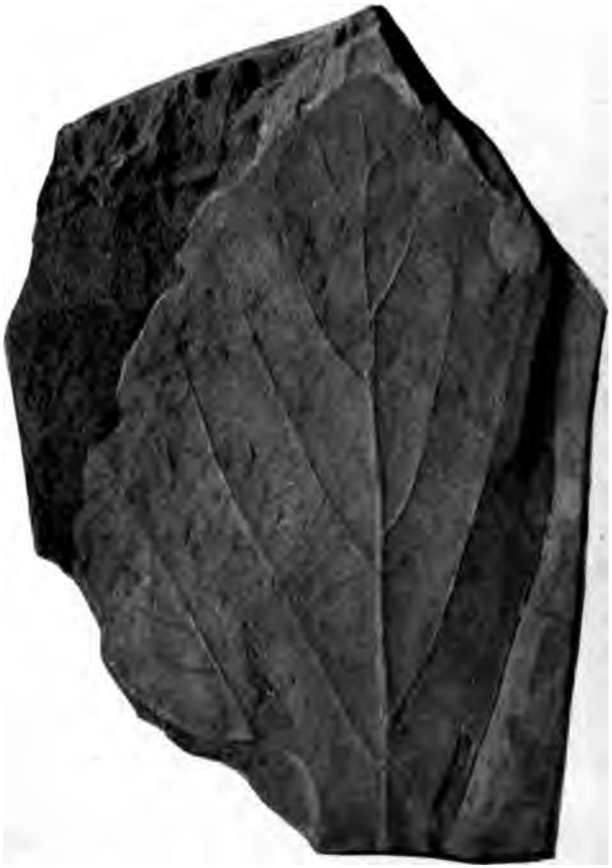

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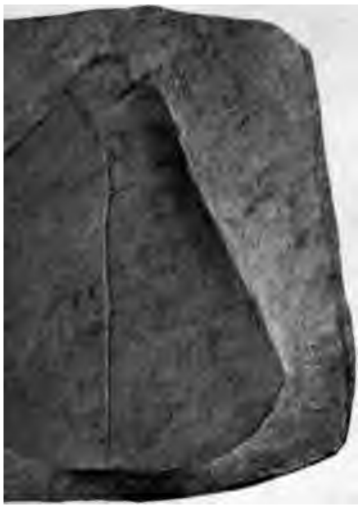
LARAMIE FLORA.

1. *Artocarpus lessigiana* (Lesquereux) Knowlton; p. 128.
2. *Ficus cockerelli* Knowlton, n. name (reproduced from Lesquereux, Leo, Tertiary flora, pl. 31, fig. 9, 1878); p. 132.

3, 3a, 4. *Ficus multinervis?* Heer (reproduced from Lesquereux, Leo, op. cit., pl. 28, figs. 7, 8, 1878); p. 138.

5. *Ficus denveriana?* Cockerell; p. 138.



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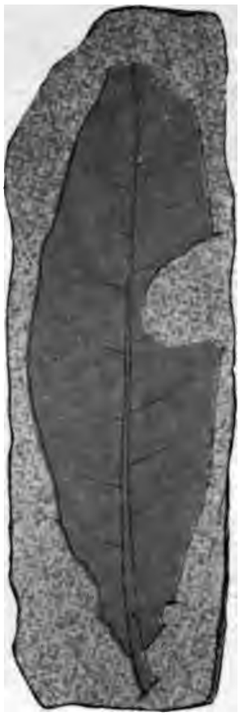

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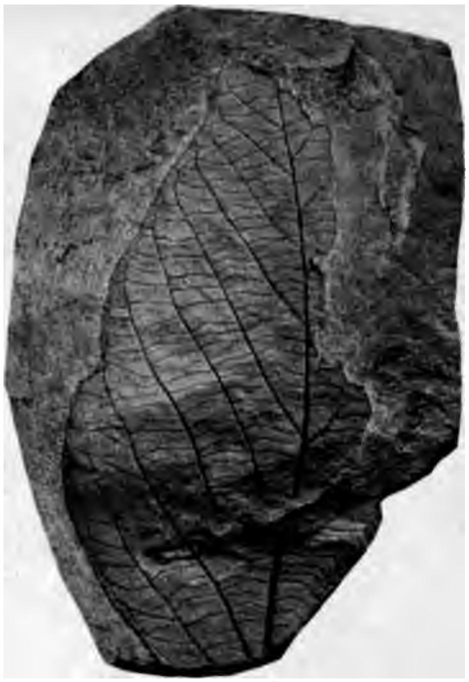

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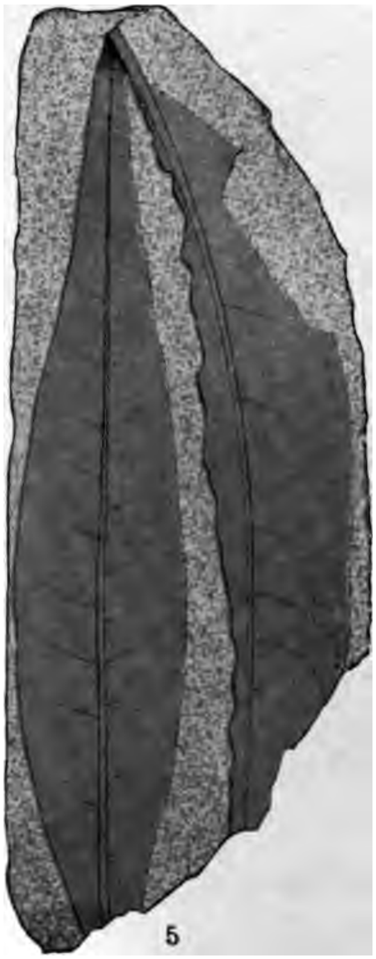

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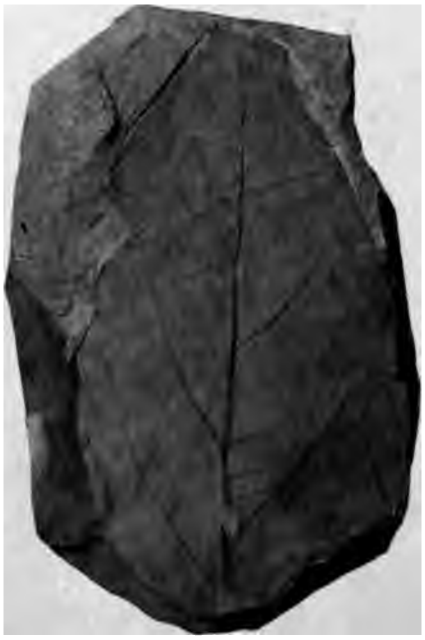

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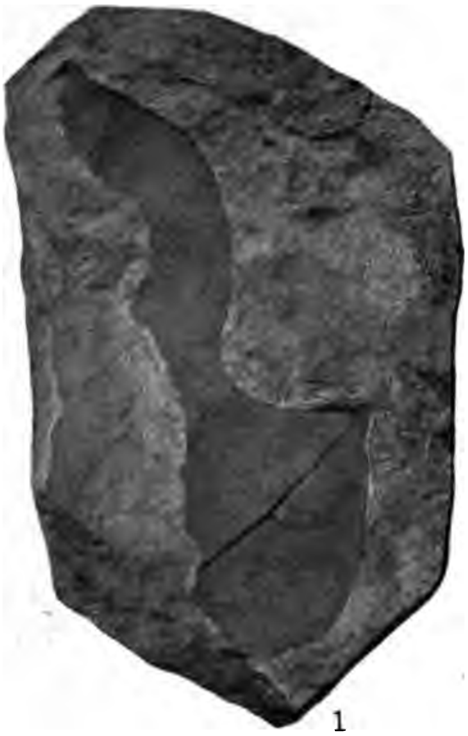
LARAMIE FLORA.

wlton, n. sp.; p. 139.
p. 139.

3–5. *Ficus navicularis* Cockerell (reproductions of figures by Lesquereux under *Ficus lanceolata:* Tertiary flora, pl. 28, figs. 1–3, 1878); p. 137.

6. *Ficus pealei* Knowlton, n. sp.; p. 131.



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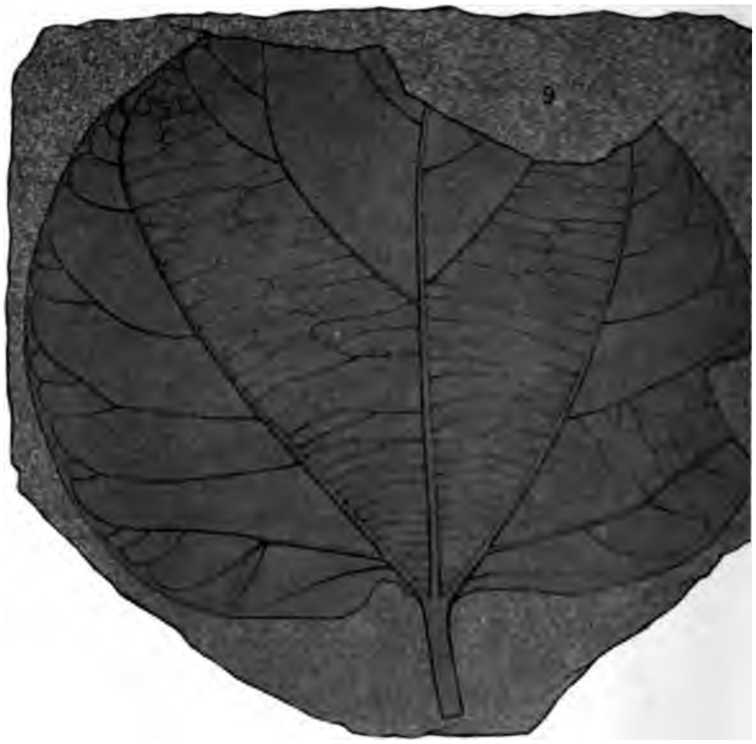

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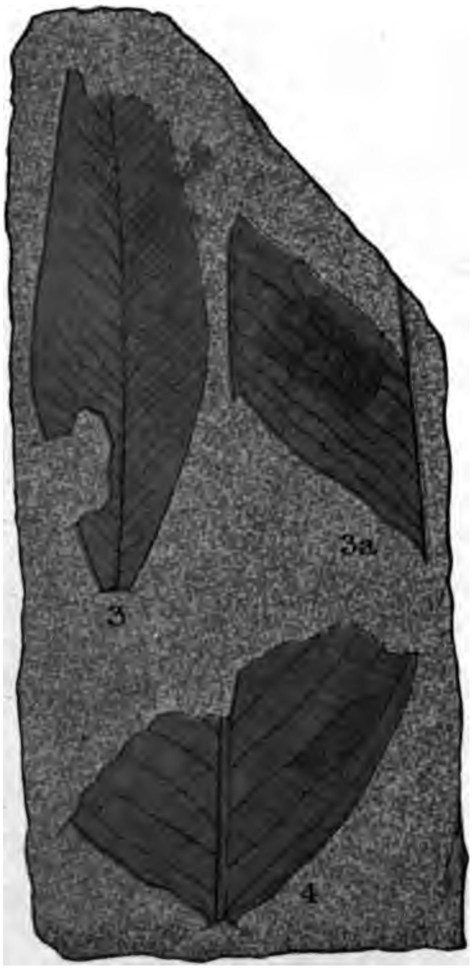

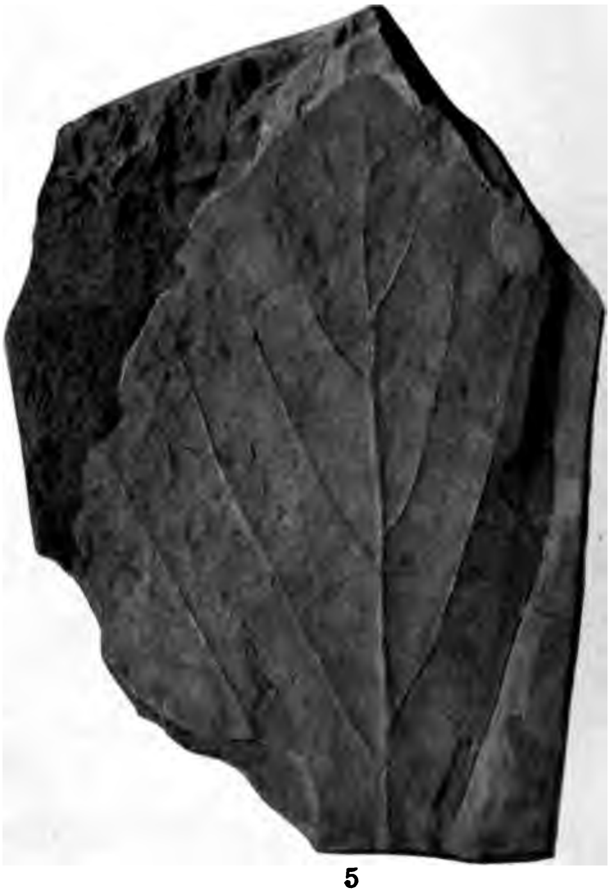

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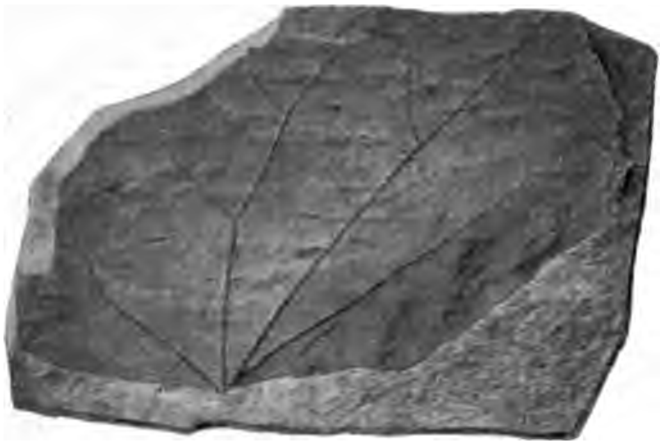
LARAMIE FLORA.

1. ***Artocarpus lessigiana*** **(Lesquereux) Knowlton; p. 128.**
2. ***Ficus cockerelli*** **Knowlton, n. name (reproduced from Lesquereux, Leo, Tertiary flora, pl. 31, fig. 9, 1878); p. 132.**

3, 3a, 4. ***Ficus multinervis?*** Heer (reproduced from Lesquereux, Loc cit., pl. 28, figs. 7, 8, 1878); p. 138.

5. ***Ficus denveriana?*** Cockerell; p. 138.



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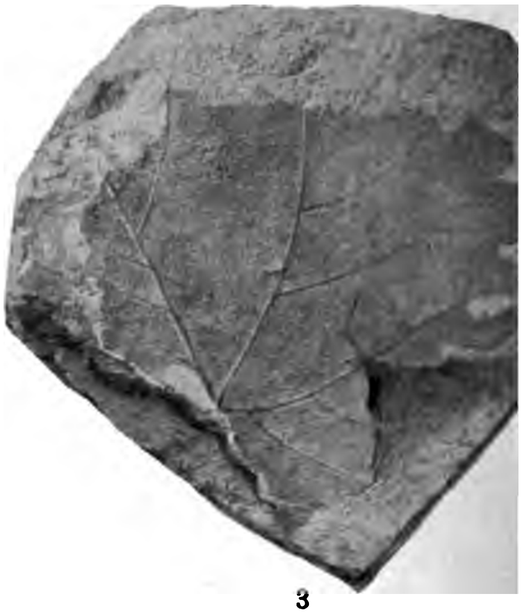

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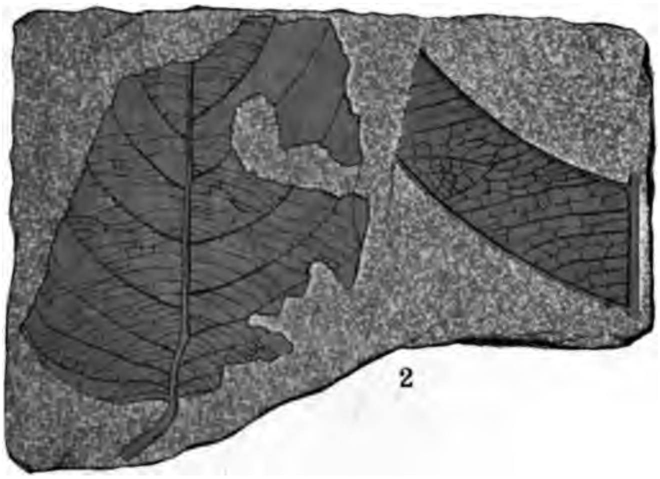

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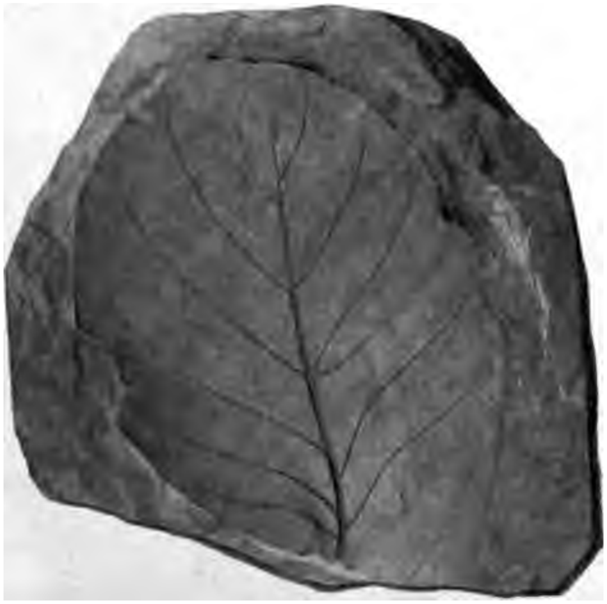

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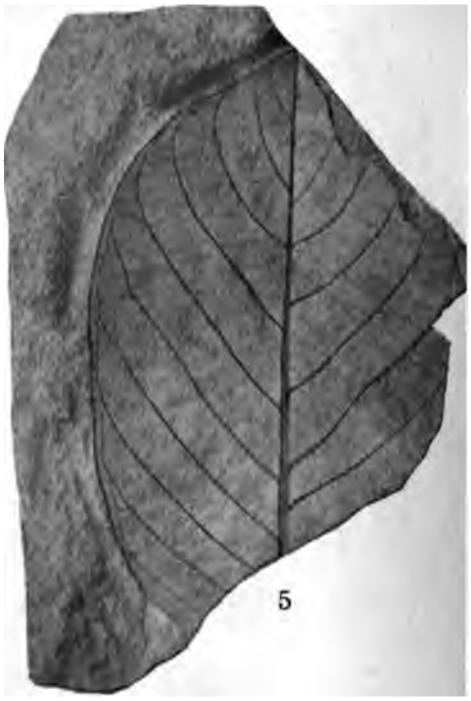

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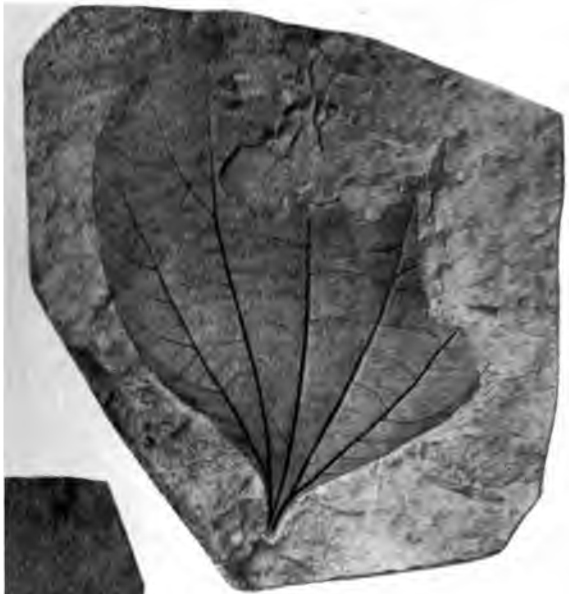
LARAMIE FLORA.

1. *Ficus leyden* Knowlton, n. sp.; p. 136.
2. *Cornus suborbifera* Lesquereux (reproduced from Lesquereux, Leo, Tertiary flora, p. 42, fig. 2, 1878); pl. 159.
3. *Dombeyopsis trivialis?* Lesquereux; p. 163.
4. *Cornus* sp.; p. 160.
5. *Cornus praeimpressa* Knowlton, n. sp.; p. 159.



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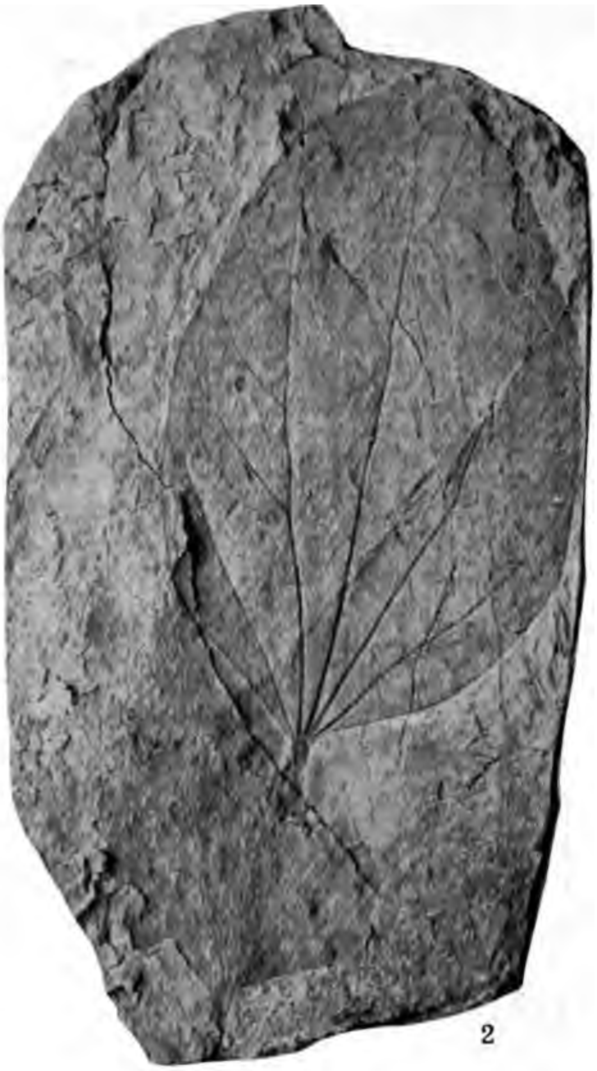

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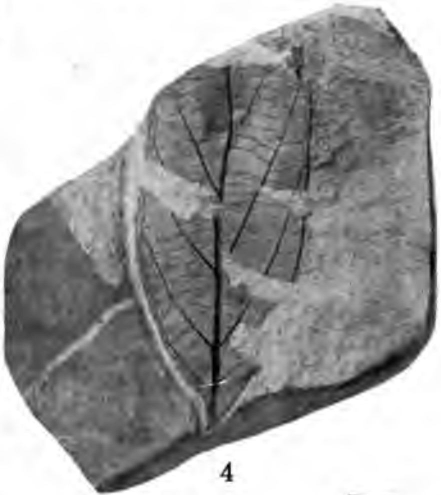

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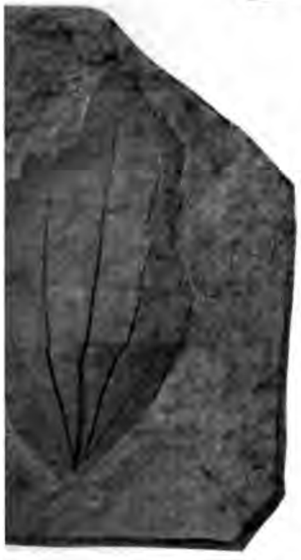

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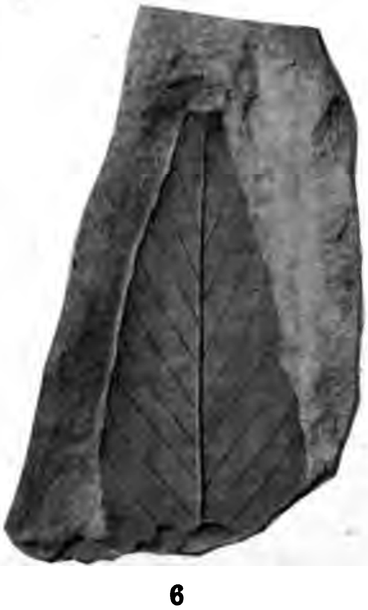

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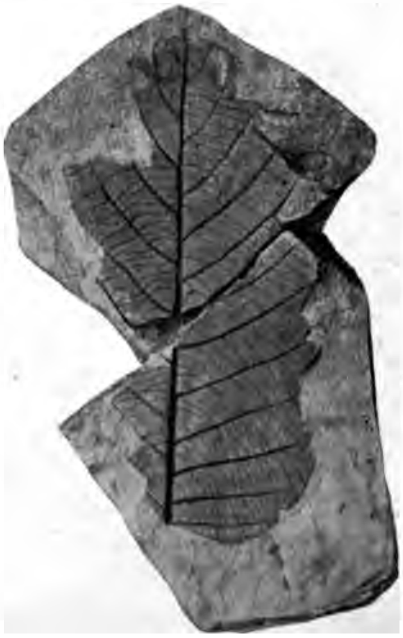

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LARAMIE FLORA.

yphus hendersoni Knowlton, n. sp.; p. 157.
us marshallensis Knowlton, n. sp.; p. 155.
us salicifolius Lesquereux; p. 154.

5. ***Zizyphus coloradensis*** Knowlton, n. sp.; p. 157.
6. ***Rhamnus brittoni*** Knowlton, n. sp.; p. 156.
7. ***Rhamnus pealei*** Knowlton, n. sp.; p. 156.

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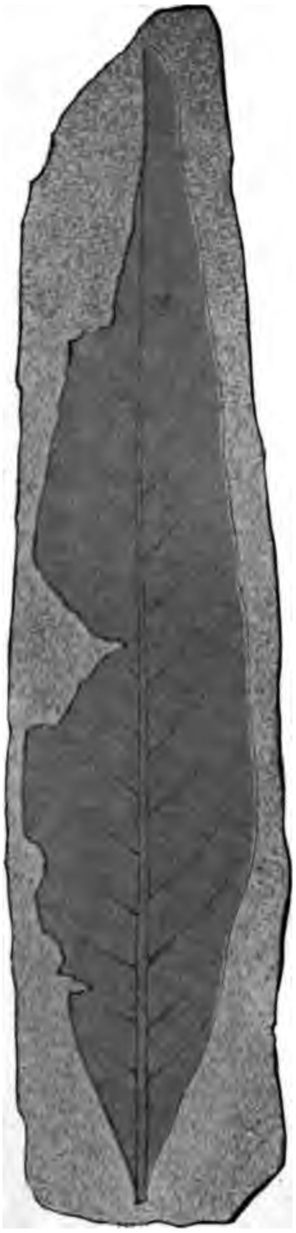

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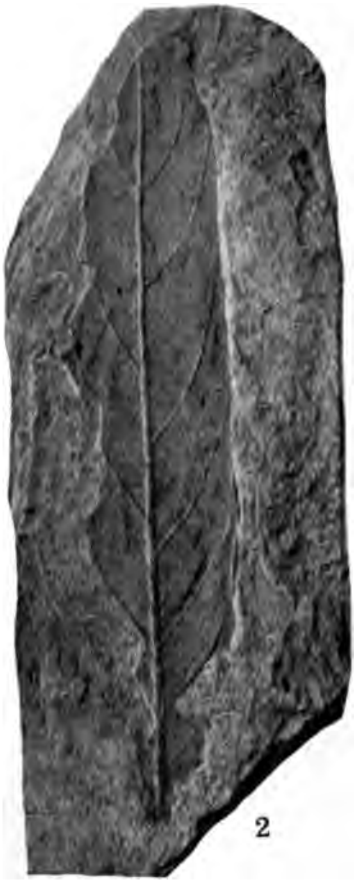

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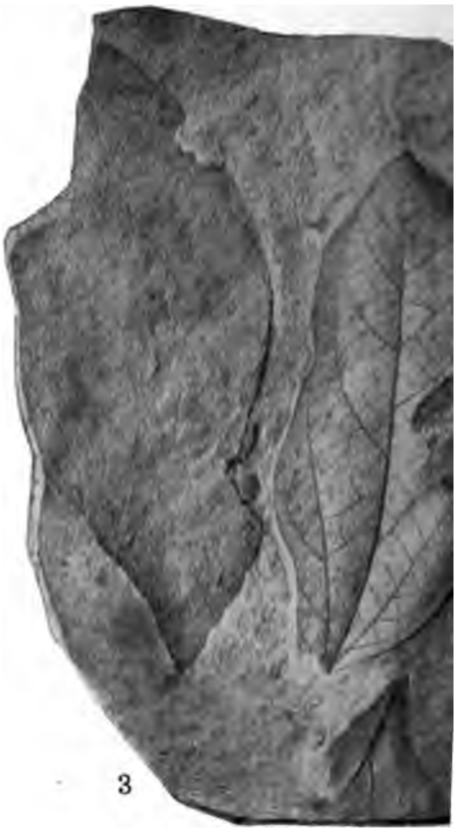

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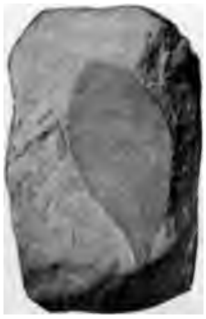

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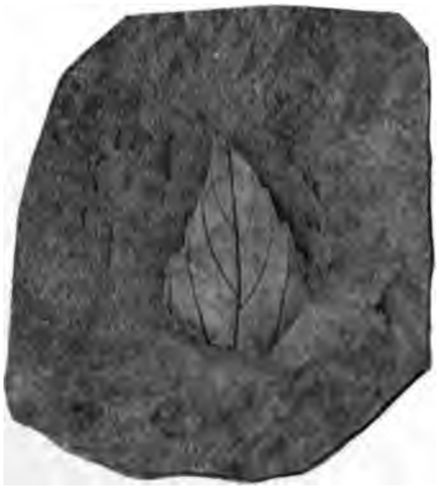

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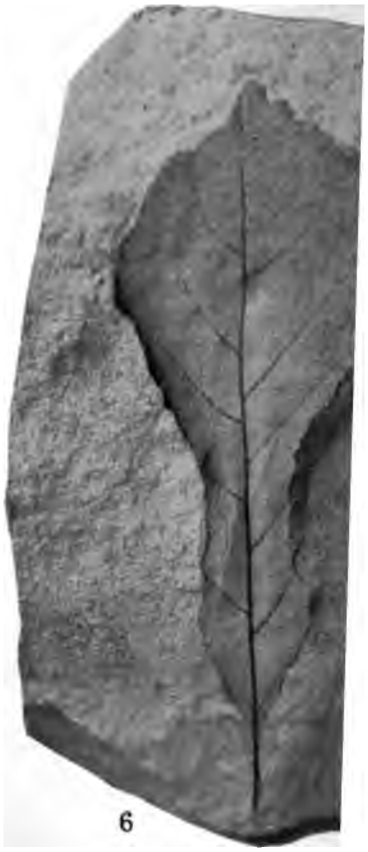

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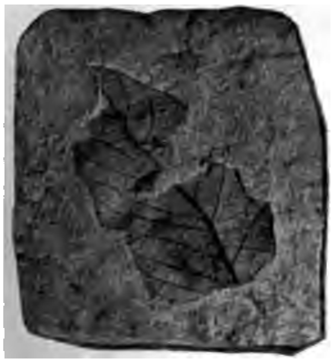
LARAMIE FLORA.

1. *Laurus wardiana* Knowlton (reproduced from Lesquereux, Leo, Tertiary flora, pl. 36, fig. 10, 1878); p. 144.
2. *Apocynophyllum? taenifolium* Knowlton, n. sp.; p. 161.
3. *Ficus impressa* Knowlton, n. sp.; p. 134.
4. *Mimosites marshallanus* Knowlton, n. sp.; p. 148.
5. *Phyllites* sp.; p. 167.
6. *Celastrinites cowanensis* Knowlton, n. sp . 149.



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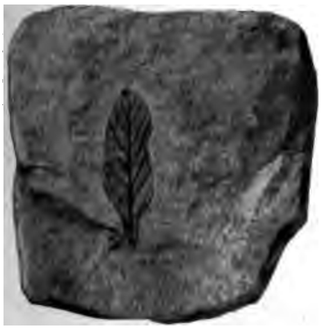

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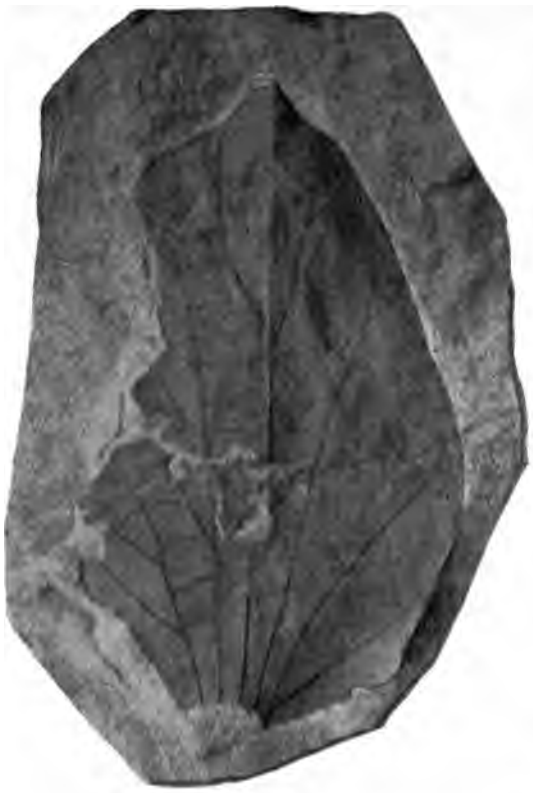

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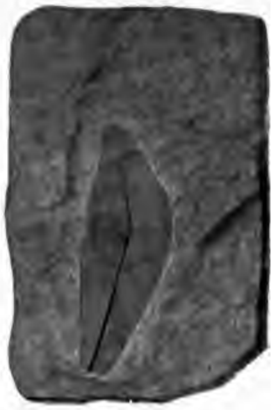

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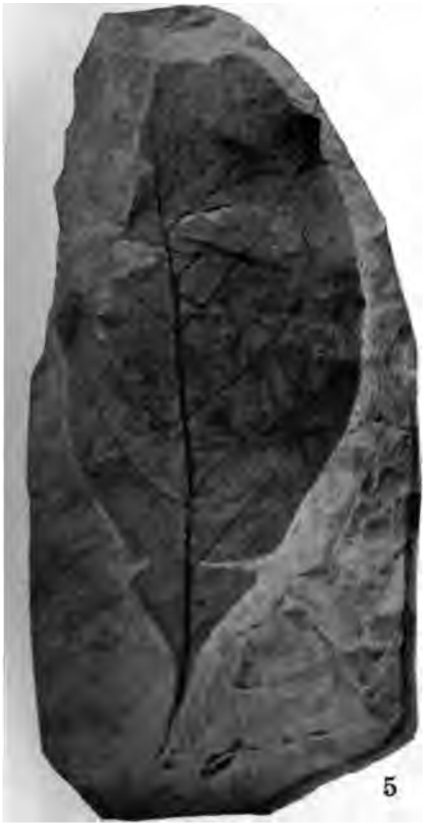

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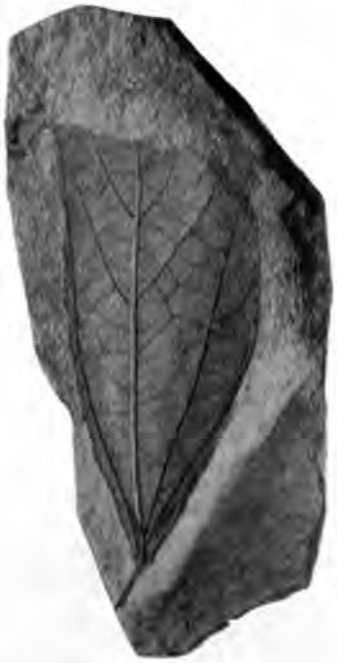

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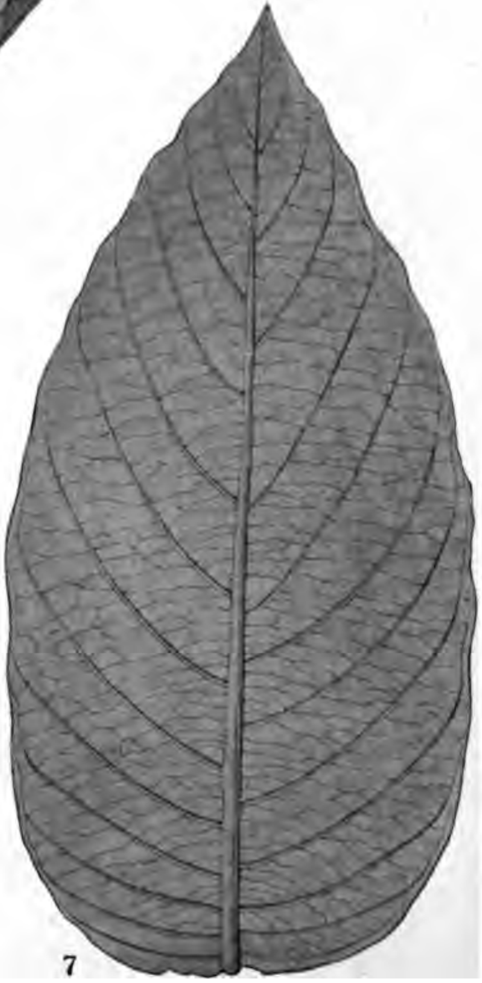

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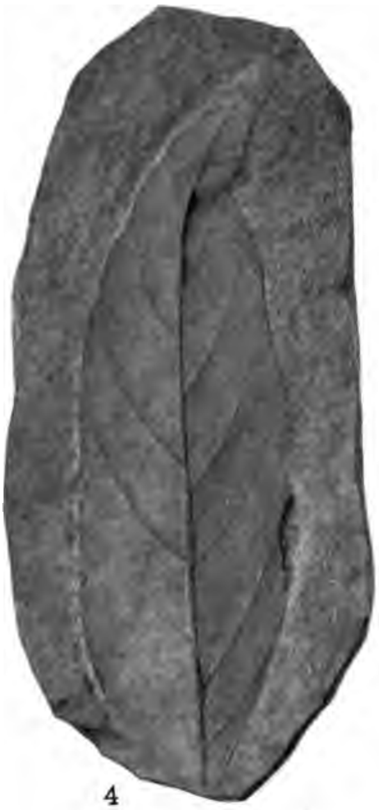
LARAMIE FLORA.

1. *Rhamnus* sp.; p. 156.
2. *Rhamnus minutus* Knowlton, n. sp.; p. 155.
3. *Zizyphus corrugatus* Knowlton, n. sp.; p. 158.
4. *Leguminosites? laramiensis* Knowlton, n. sp.; p. 148.
5. *Diospyros berryana* Knowlton, n. sp.; p. 161.
6. *Cinnamomum affine* Lesquereux; p. 145.
7. *Anona robusta* Lesquereux (reproduced from Lesquereux, Leo, Cretaceous and Tertiary floras, pl. 20, fig. 4, 1883); p. 143.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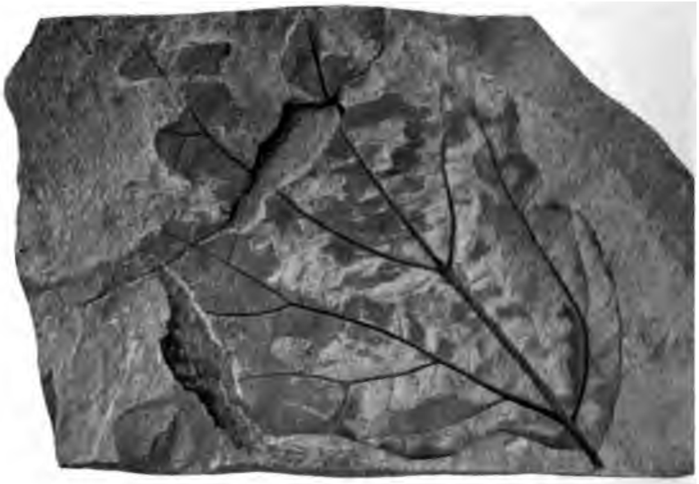
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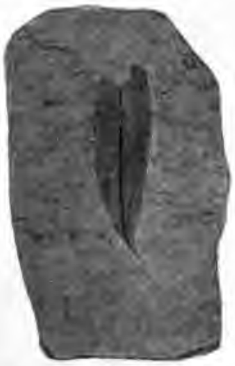
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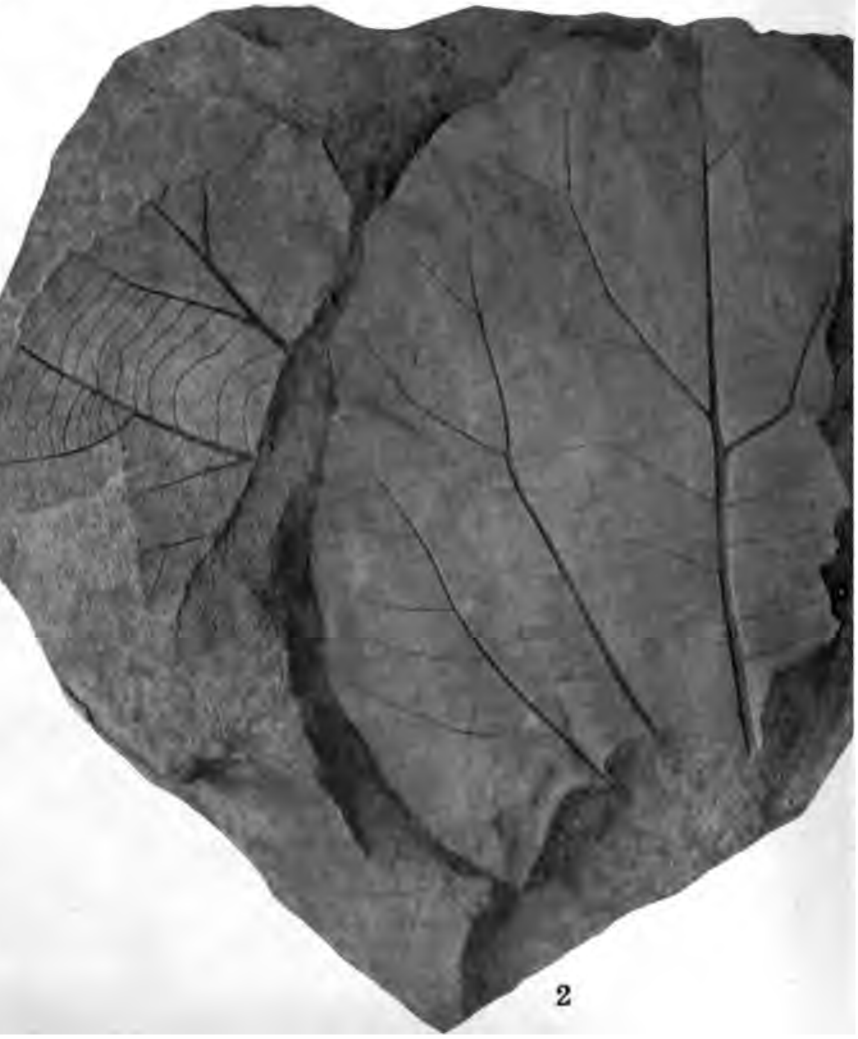
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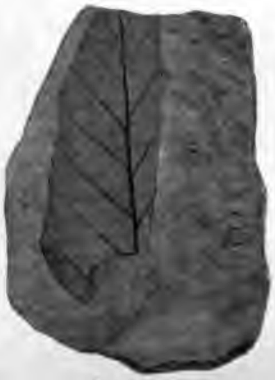
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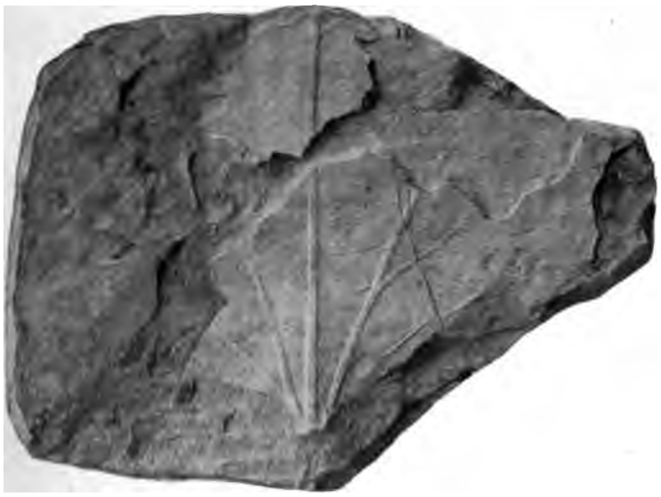
LARAMIE FLORA.

1. *Zizyphus minutus* Knowlton, n. sp.; p. 158.
2. *Phyllites dombeyopsoides* Knowlton, n. sp.; p. 166.
3. *Rhamnus goldianus?* Lesquereux; p. 154.
4. *Anona coloradensis* Knowlton, n. sp.: p. 143.
5. *Phyllites leydenianus* Knowlton, n. sp.: p. 165.



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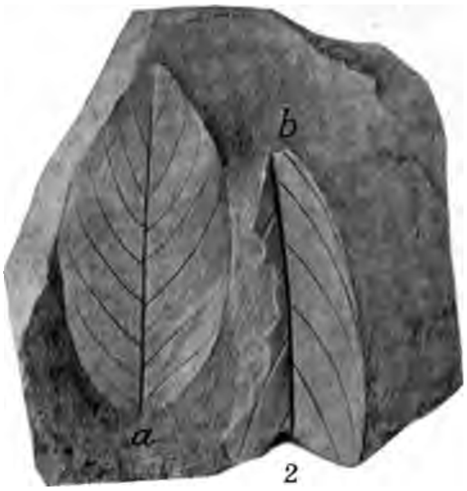

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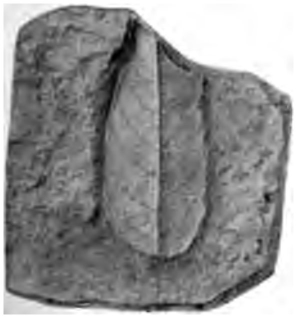

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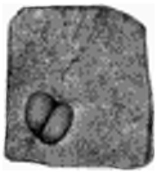

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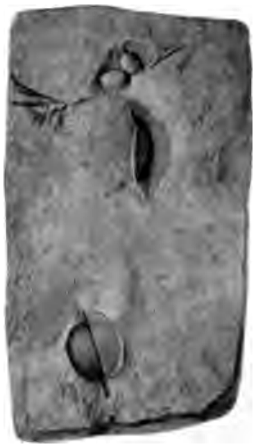

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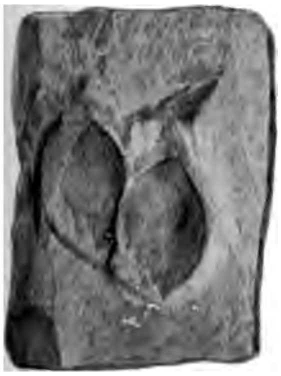

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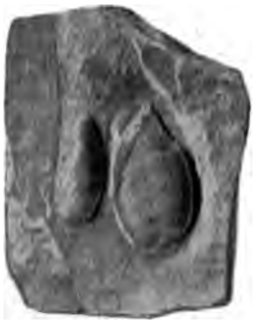

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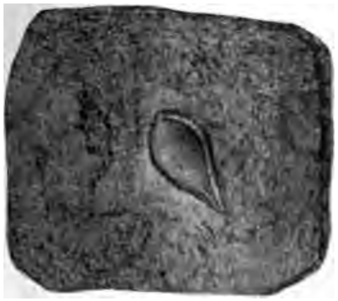

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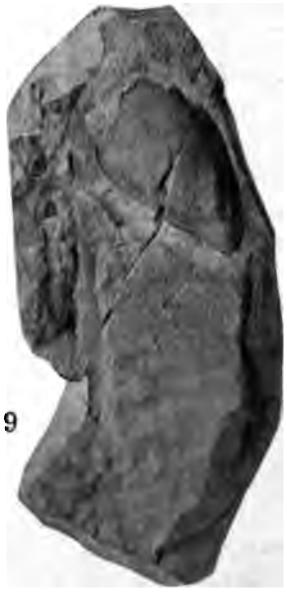

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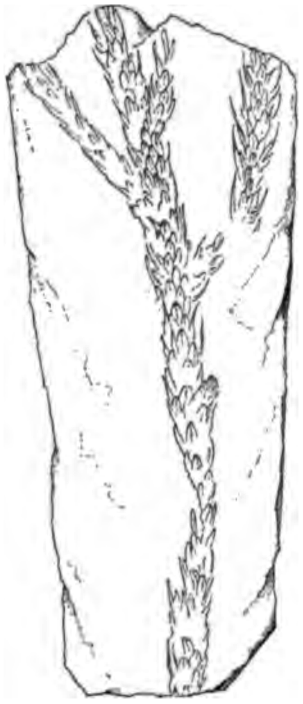
LARAMIE FLORA.

1. *Phyllites* sp.; p. 167.
2a. *Cornus praeimpressa* Knowlton, n. sp.; p. 159.
2a. *Rhamnus salicifolius* Lesquereux; p. 154.
3. *Cassia? laramiensis* Knowlton, n. sp.; p. 148.
4, 5. *Leguminosites columbianus* Knowlton, n. sp.; p. 147.
6–8. *Carpites lakesii* Knowlton, n. sp.; p. 164.
9. *Leguminosites? coloradensis* Knowlton, n. sp.; p. 147.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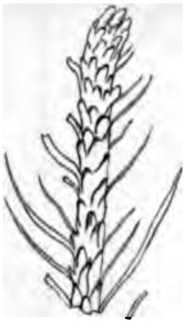
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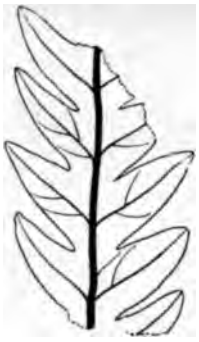
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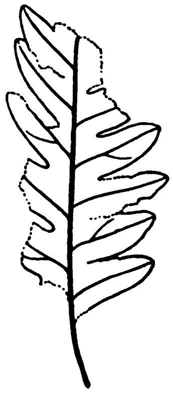
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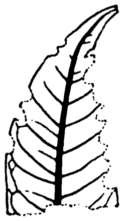
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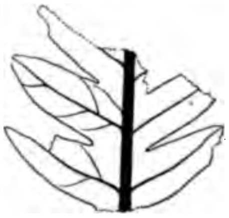
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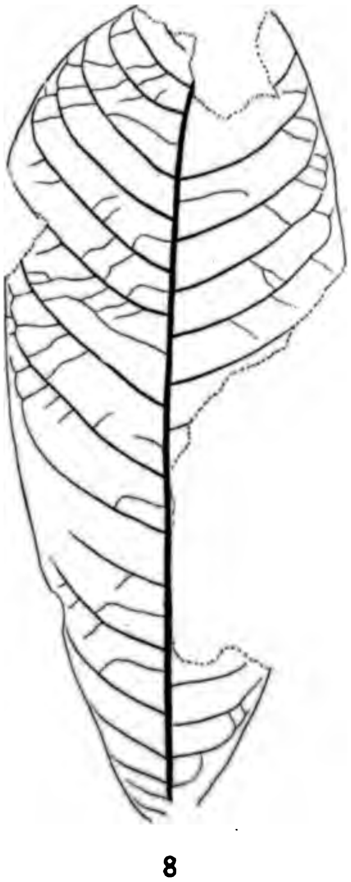
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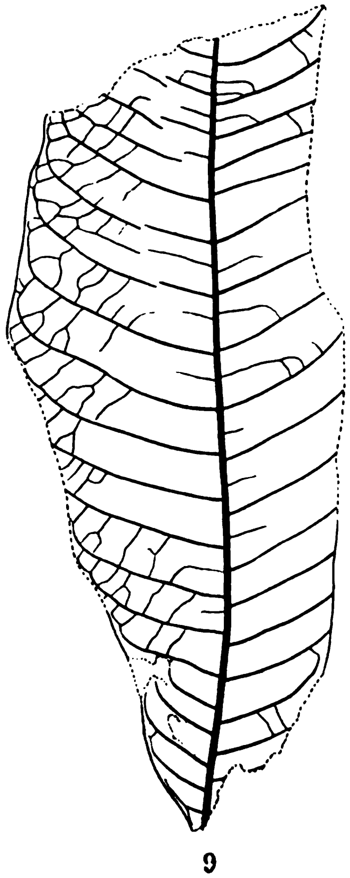
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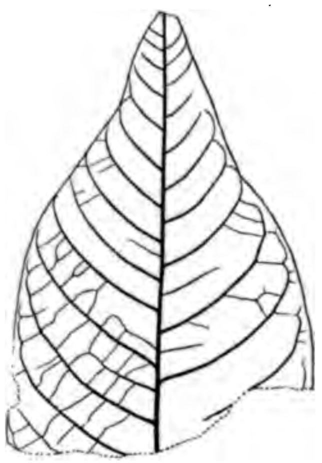
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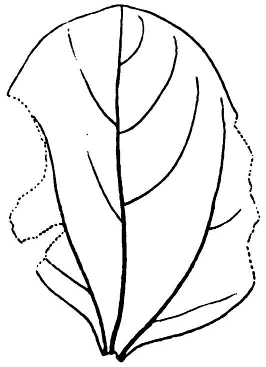
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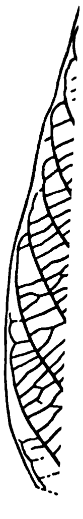
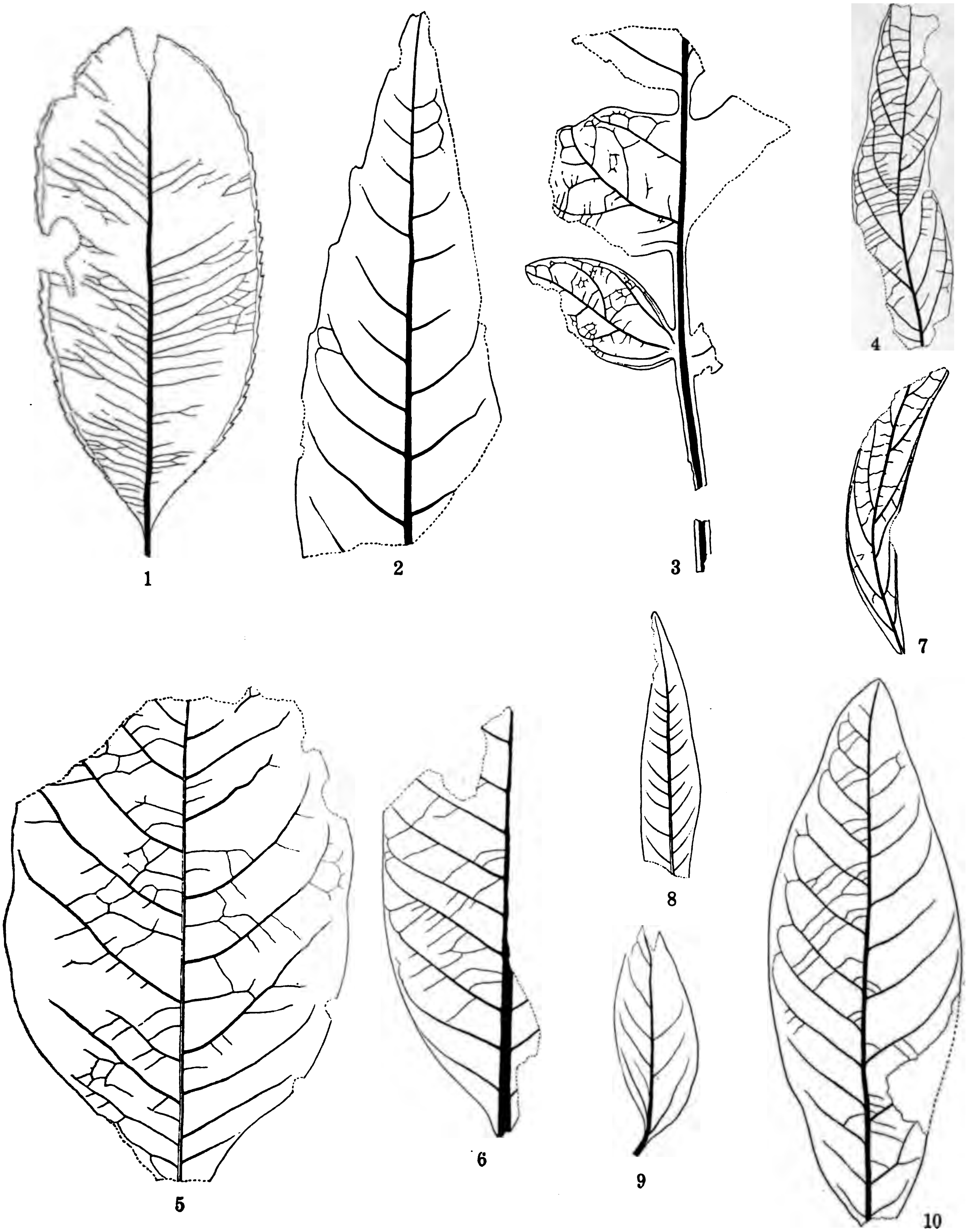


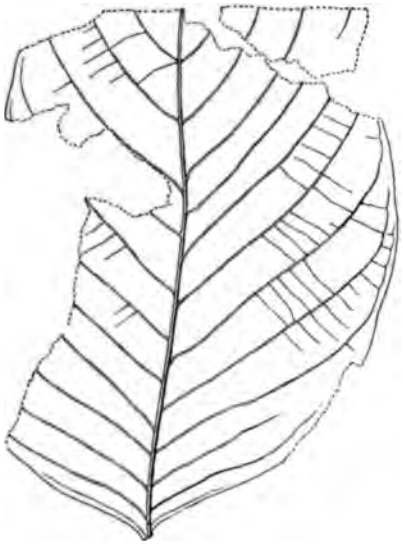
LARAMIE FLORA.

1, 2. ***Sequoia reichenbachi*** **(Geinitz) Heer; p. 114.**
3–5. ***Dryopteris? carbonensis*** **Knowlton, n. sp.; p. 110.**
6. ***Cyperacites? hillsii*** **Knowlton, n. sp.; p. 118.**
7. ***Phyllites*** **sp. (Not described in text.)**
8–10. ***Juglans newberryi*** Knowlton, n. sp.; p. 120.
11. ***Dombeyopsis obtusa*** Lesquereux; p. 162.
12. ***Juglans laramiensis*** Knowlton, n. sp.; p. 120.



LARAMIE FLORA.

1. *Myrica oblongifolia* Knowlton, n. sp.; p. 124.
2. *Quercus eximia* Knowlton, n. sp.; p. 127.
3. *Artocarpus liriodendroides* Knowlton, n. sp.; p. 129.
4. *Ficus? smithsoniana?* (Lesquereux) Lesquereux; p. 130.
5. *Juglans praerugosa* Knowlton, n. sp.; p. 121.
6. *Ficus arenacea* Lesquereux; p. 140.
7. *Laurus lanceolata* Knowlton, n. sp.; p. 143.
8. *Salix brittoniana* Knowlton, n. sp.; p. 125.
9. *Ficus dalmatica* Ettingshausen; p. 135.
10. *Magnolia marshalli* Knowlton, n. sp.; p. 142.



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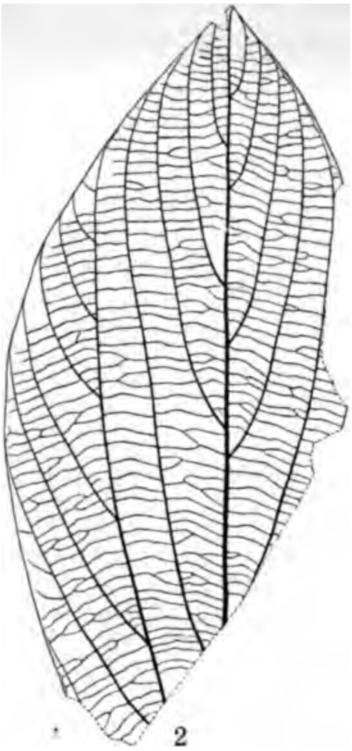

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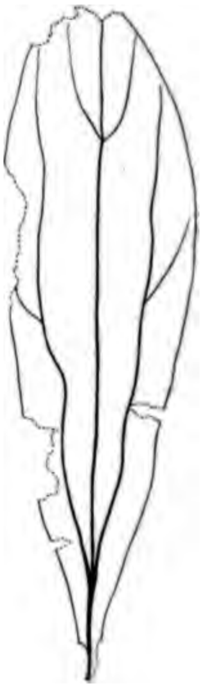

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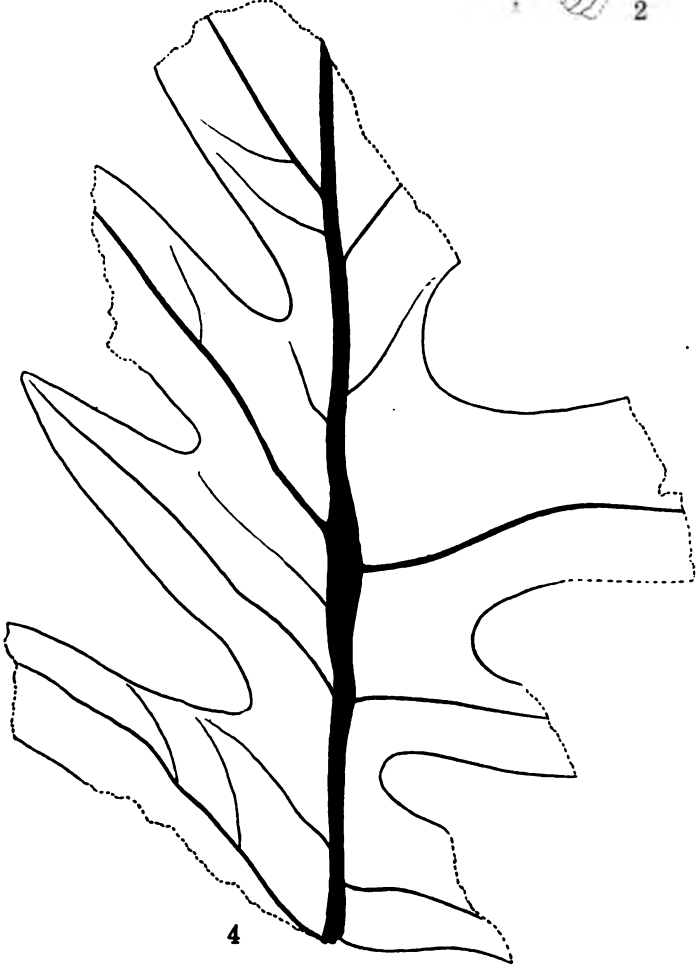

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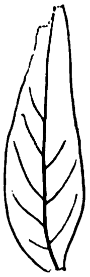

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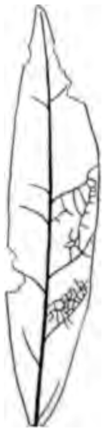

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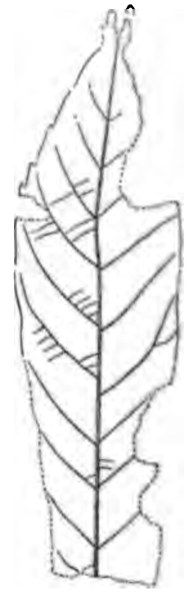

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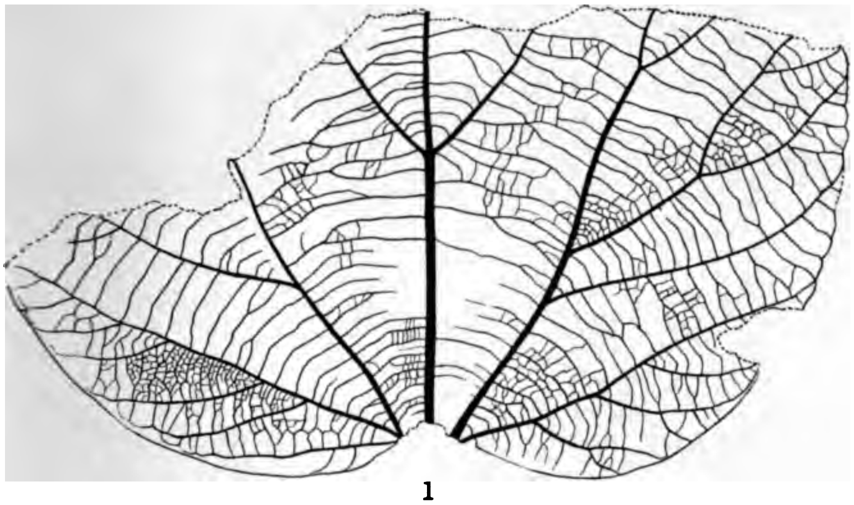
LARAMIE FLORA.

1. *Ficus coloradensis* Cockerell; p. 134.
2. *Ficus praeplanicostata* Knowlton, n. sp.; p. 133.
3. *Cinnamomum laramiense* Knowlton, n. sp.; p. 146.
4. *Artocarpus lessigiana* (Lesquereux) Knowlton; p. 128.
5. *Ficus dalmatica?* Ettingshausen; p. 135.
6. *Laurus lakesii* Knowlton, n. sp.; p. 144.
7. *Fraxinus? princetoniana* Knowlton, n. sp.; p. 161



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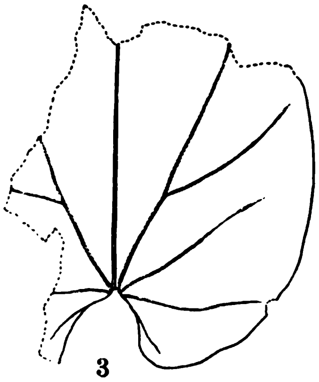

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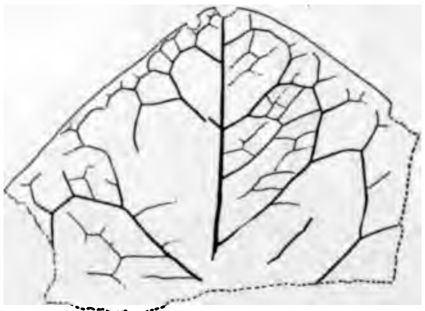

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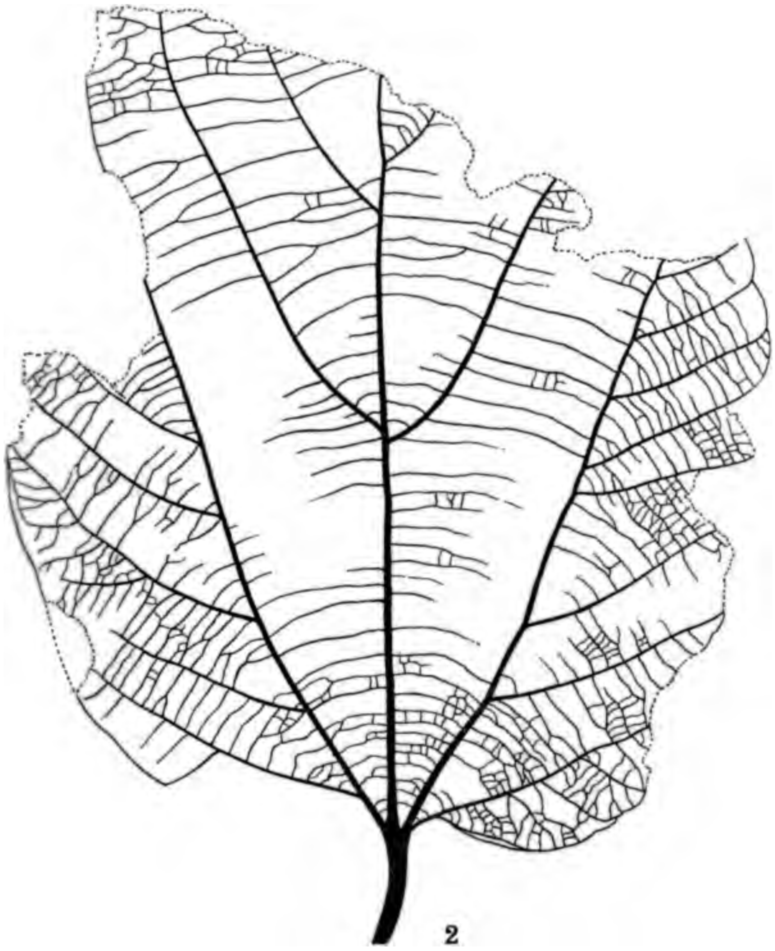

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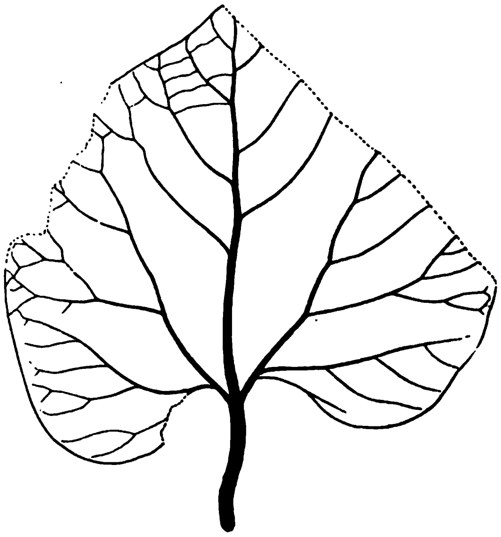

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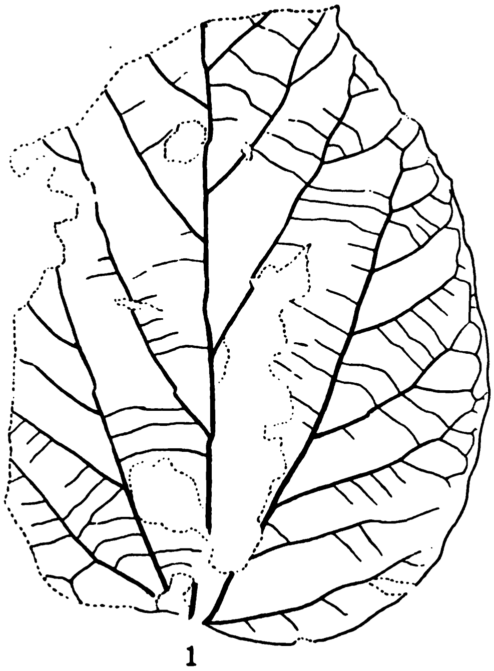
LARAMIE FLORA.

1, 2. *Ficus cockerelli* Knowlton, n. name; p. 132.

3-5. *Aristolochia brittoni* Knowlton, n. sp.; p. 140.



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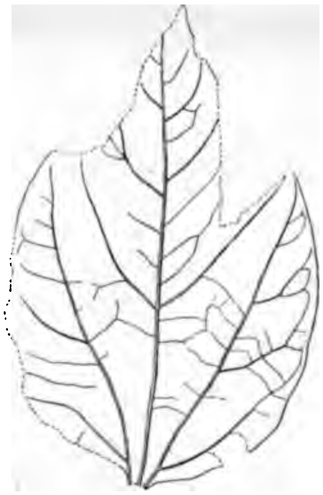

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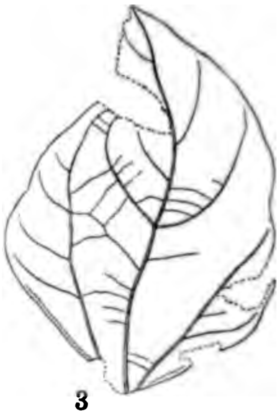

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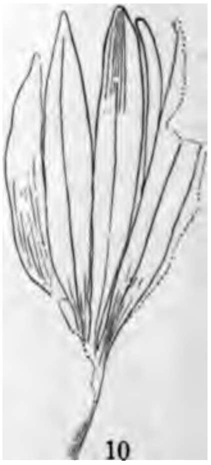

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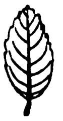

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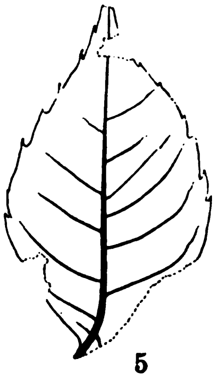

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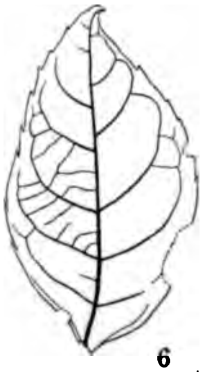

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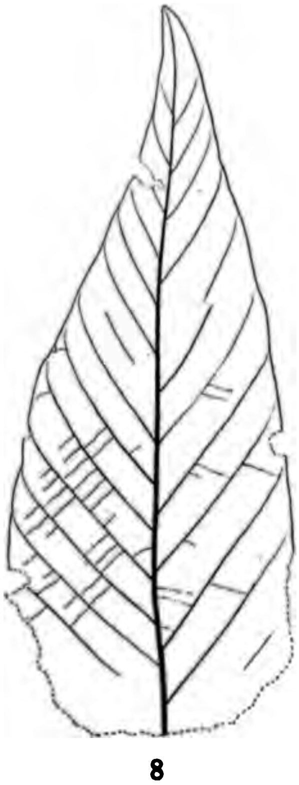

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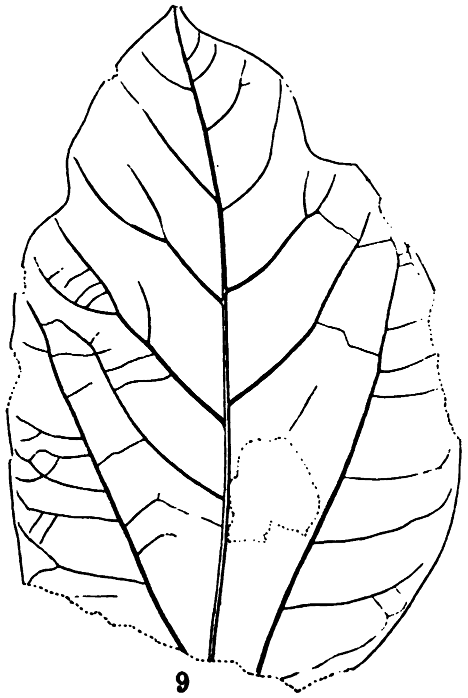

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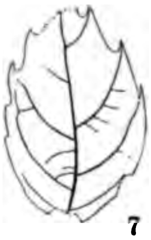

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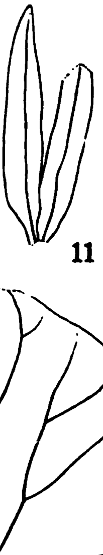

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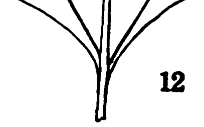

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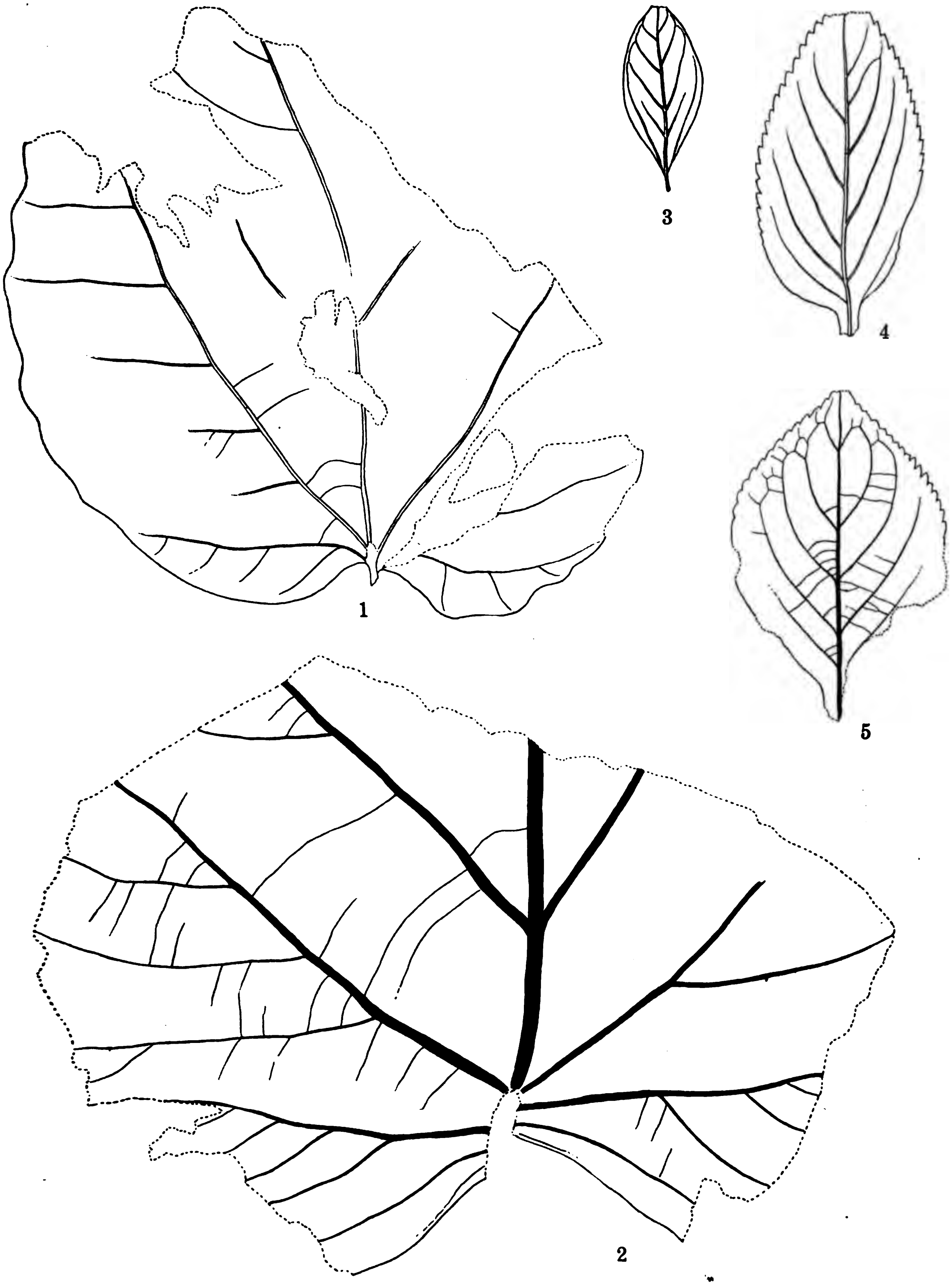

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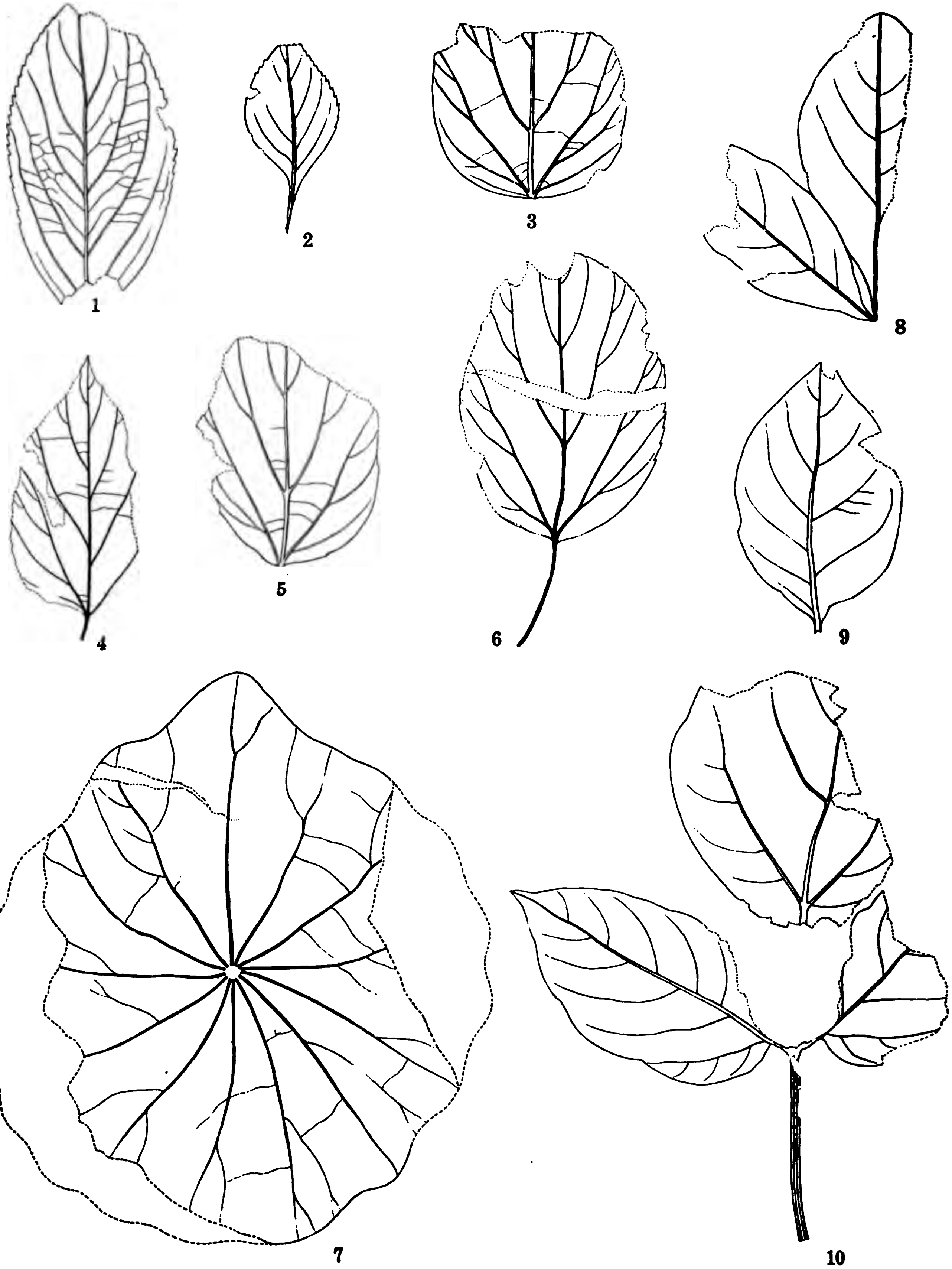

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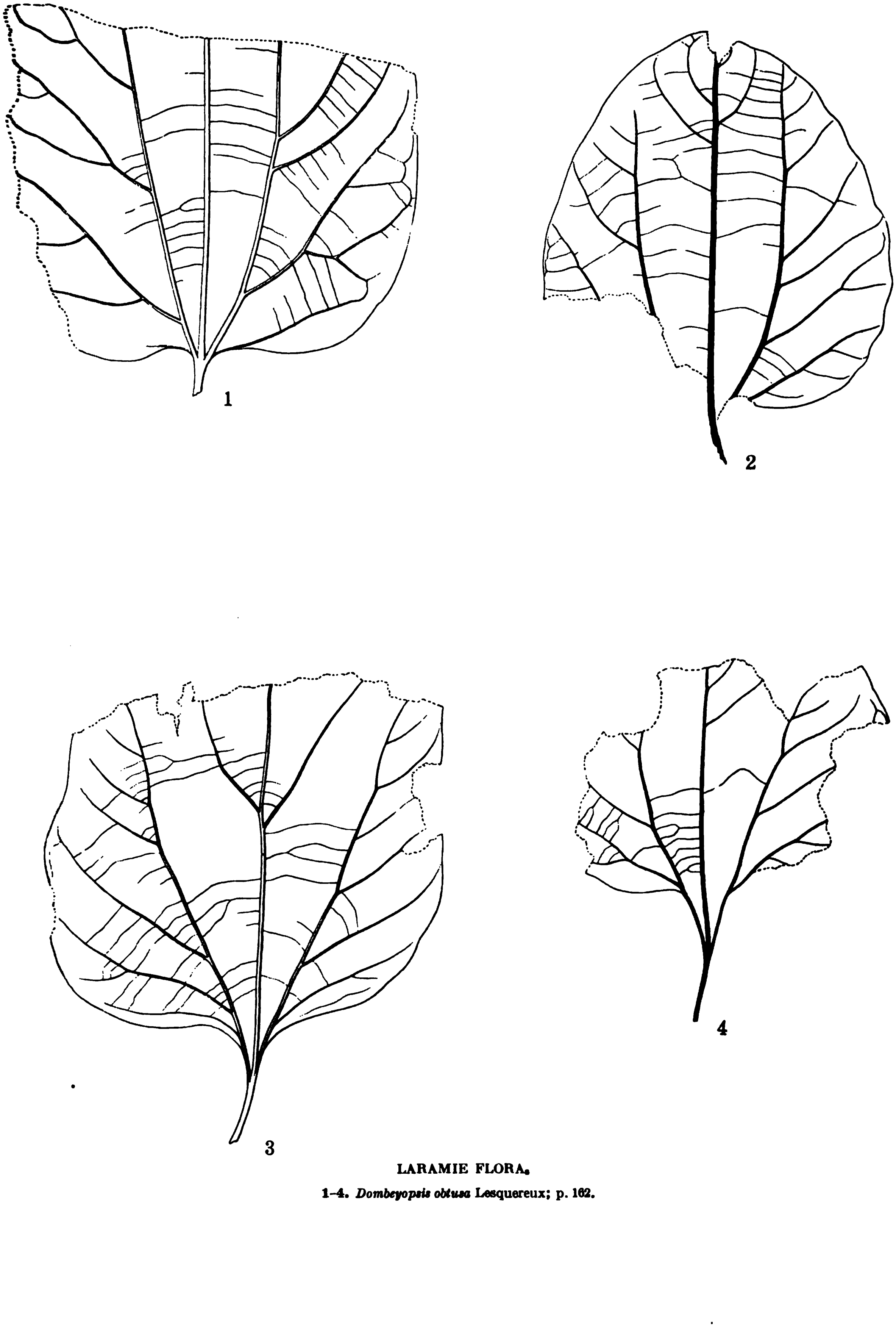

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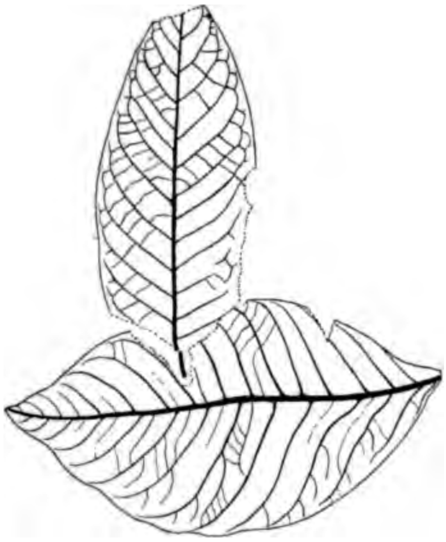

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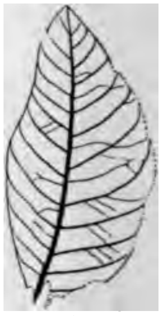

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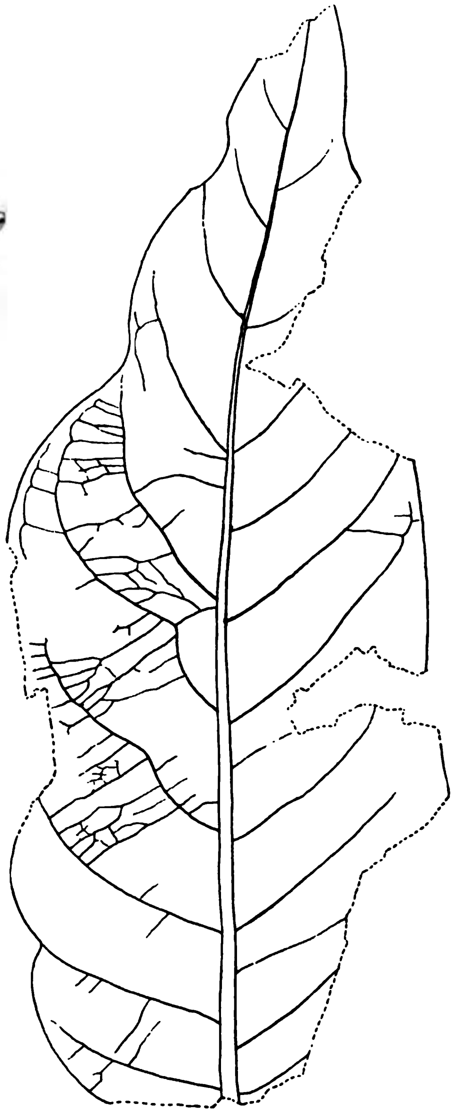

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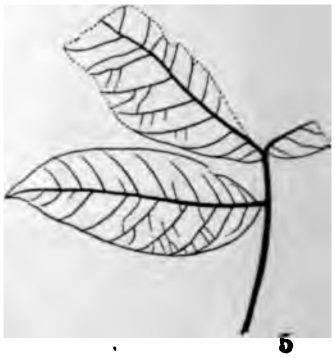

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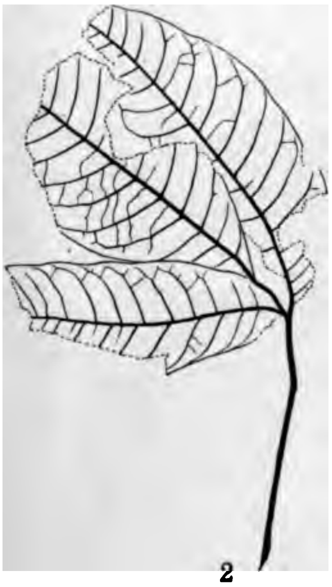

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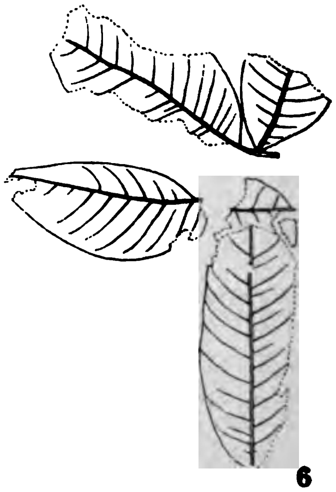

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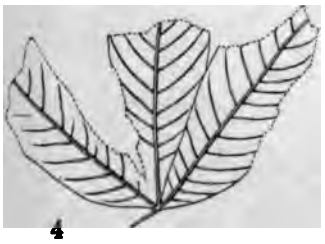

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1922

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DAVID WHITE, CHIEF GEOLOGIST

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SHORTER CONTRIBUTIONS TO GENERAL GEOLOGY, 1922.

ADDITIONS TO THE FLORA OF THE WILCOX GROUP.

By EDWARD WILBER BERRY.

A rather full account of the extensive flora contained in the lower Eocene strata of the Mississippi embayment which are referred to the Wilcox group was published in 1916.[1] At that time it was not possible to obtain sections of the numerous specimens of petrified wood that had been collected from these beds. These woods have since been sectioned and studied, and it seems eminently desirable to place the results of this study on record, for although much of the material had suffered greatly from decay before silicification, some of it is fairly well preserved and shows, among other results, that conifers were individually much more plentiful during Wilcox time than would be inferred from the almost total absence of their foliage in the very large collections of remains of this class that have been studied.

Moreover, these coniferous woods show well-marked seasonal rings, indicating periodicity in the climate, which can be explained as due either to severity of winters or to a seasonal rainfall and a regularly recurring dry season. As the facies of the flora appears to preclude the first alternative, the second would seem established, except that the general character of the flora is equally opposed to this alternative. As both the pines and the bald cypress in the existing flora at their southern limit in peninsular Florida show annual rings, it seems to me that a somewhat similar winter season must be predicated for the Wilcox. This does not mean annual snow or frost, although freezes may have occurred at intervals of years. Severity is a relative term, and I would not expect the Wilcox climate, even at the north end of the embayment, near the present mouth of the Ohio, to have been any more severe during the winter than the present climate, for example, of Fort Pierce, in the southern Indian River region of peninsular Florida. This conclusion is practically the same as that arrived at in the previous analysis of the Wilcox flora.

Very little has heretofore been known of the Wilcox flora in the Texas area. In Professional Paper 91 Wilcox plants were recorded from only three localities in Texas, and two of these—Old Port Caddo Landing, in Harrison County, and Sabine River in Sabine County—are in the extreme eastern part of the State. The third and westernmost locality from which Wilcox plants had been recorded is on Calaveras Creek in Wilson County. That the lack of fossils from the Wilcox in the region between San Antonio and the Rio Grande was due entirely to lack of exploration was shown by a short trip through this region during 1921. Although fossil plants are not so common there as farther east, because the upper Wilcox, which alone crops out, contains a large proportion of sandy beds, long ago recognized as the Carrizo sandstone, several collections were obtained. The age of the Carrizo sandstone has heretofore been somewhat uncertain. Referred originally to the Wilcox, it has been considered to be of Claiborne age by several Texas geologists. The plants found in the Carrizo sandstone, as well as those found both above and below it near the Rio Grande, definitely settle its upper Wilcox age. These will be discussed on a subsequent page.

In addition, a few collections have been sent to me from time to time from new localities, and I am particularly indebted to Mr. O. M. Ball for a large collection obtained near Mansfield, La.

---

[1] Berry, E. W., U. S. Geol. Survey Prof. Paper 91, 1916.

In Professional Paper 91 I recorded 342 species of plants from the Wilcox. In Professional Paper 108–E, published in 1917, species of *Zamia* and *Nelumbo* were added. The present contribution includes additional plants, but as a number of supposed species of *Ficus* are now reduced to synonymy, the total additions amount to 9, making 353 as the number of species now recognized in the Wilcox flora.

The descriptions in the present paper include both lauraceous and sterculiaceous woods, also strikingly well preserved and characteristic lauraceous fruits. Other novelties are a liverwort (*Marchantites,*) the fern genus *Dryopteris*, palm nuts, the genus *Monocarpellites* (which helps to prove that the lignites of Brandon, Vt., are Eocene and not Miocene), an interesting fruit of the otherwise unrepresented family Icacinaceae, and a second which is referred with some hesitation to the family Anacardiaceae.

The upper Wilcox plant-bearing bed in the Grenada formation near Grenada, Grenada County, Miss., is at the southernmost point at which determinable fossil plants had been found in the Wilcox in the eastern Gulf area. Much interest therefore attaches to a small collection made recently in southern Alabama by C. W. Cooke and J. A. Gardner. The exact locality is at the wagon bridge on Claybank Creek 1 mile west of Clayhatchee, Dale County. This is about 300 miles southeast of Grenada and east of the typical localities of marine Wilcox beds. The matrix is a sandy brown clay, and the contained leaves are poor and fragmentary. Representatives of four different species are recognizable, although but one of these is determinable, and this represents a perfect leaflet of *Mimosites variabilis* Berry.

The following species are recorded from the Spinks pit, near Paris, Henry County, Tenn. The specimens occur in a gray plastic clay from which the entire leaves can be washed and mounted in balsam between glass, thus forming very exceptional specimens:

Monocarpellites perkinsi Berry.
Nectandra glenni Berry.
Oreodaphne salinensis Berry.
Sapindus mississippiensis Berry.

The following are additions to the flora from a locality 1 mile south of Grand Junction, Tenn.:

Sabalites grayanus Lesquereux.
Oreodaphne puryearensis Berry.

At the time of publication of Professional Paper 91 the collections obtained 4 miles southwest of Boydsville, Ark., were lost, and as they had only received a preliminary study the list of species from that locality was very incomplete. These collections have since received careful study, which has shown that *Ficus denveriana* should be omitted from this florule and that the following species should be added:

Anacardites puryearensis Berry.
Apocynophyllum mississippiensis Berry.
Apocynophyllum wilcoxense Berry.
Cinnamomum oblongatum Berry.
Coccolobis uviferafolia Berry.
Cyperacites sp.
Engelhardtia ettingshauseni Berry.
Ficus mississippiensis (Lesquereux) Berry.
Ficus pseudocuspidata Berry.
Ficus puryearensis Berry.
Hiraea wilcoxiana Berry.
Juglans schimperi Lesquereux.
Magnolia leei Knowlton.
Myrcia vera Berry.
Nectandra puryearensis Berry.
Oreodaphne mississippiensis Berry.
Palmocarpon butlerensis Berry.
Sapindus mississippiensis Berry.
Ternstroemites eolignitic us Berry.

These all serve to emphasize the late Wilcox age of the Boydsville florule.

At a locality near Jacksonville, in Pulaski County, Ark., L. W. Stephenson collected the following species, which prove the outcrop to be of upper Wilcox age:

Celastrus taurinensis Ward.
Cordia? lowii Berry?
Dillenites microdentatus (Hollick) Berry.
Euonymus splendens Berry.
Ficus harrisiana Hollick.
Marchantites stephensoni Berry.
Nectandra cf. N. glenni Berry.
Nectandra sp.
Oreodaphne obtusifolia Berry.

In material from a gray plastic clay at 304 to 319 feet below the surface in a well at Negreet, 9 miles southwest of Many, Sabine Parish, La., I recognized the two following Wilcox species:

Pteris pseudopinnaeformis Lesquereux.
Simaruba eocenica Berry.

The following plants were collected by O. M. Ball at the Goss pit, half a mile east of Mansfield, De Soto Parish, La.:

Apocynophyllum mississippiensis Berry.
Artocarpoides balli Berry.
Bombacites formosus Berry.
Diospyros wilcoxiana Berry.
Dryopteris cladophleboides Knowlton.
Dryophyllum sp.
Euonymus splendens Berry.
Ficus artocarpoides Lesquereux.
Ficus mississippiensis (Lesquereux) Berry.
Inga laurinafolia Berry.
Juglans schimperi Lesquereux.
Laurus vera Berry.
Magnolia angustifolia Newberry.
Magnolia leei Knowlton.
Metopium wilcoxianum Berry.
Oreodaphne salinensis Berry.
Rhamnus eolignitieus Berry.
Rhamnus marginatus Lesquereux.
Rhamnus marginatus apiculatus Berry.
Rhamnites knowltoni Berry.
Sterculia wilcoxensis Berry.
Sterculiocarpus eocenicus Berry.
Terminalia hilgardiana (Lesquereux) Berry.
Terminalia lesleyana (Lesquereux) Berry.

The following were contained in a collection from a locality 10 miles south-southwest of Palestine, Anderson County, Tex., in Post Oak Prairie, 2 miles south of Needmore (collectors, O. B. Hopkins and O. C. Funderbunk):

Canavalia eocenica Berry?
Lygodium binervatum (Lesquereux) Berry.
Nectandra pseudocoriacea Berry?

The following were sent in by the last-named collectors from the Butler (or West Point) salt dome, in the eastern part of Freestone County, near Trinity River, 6 miles northeast of Oakville, Tex.:

Mespilodaphne coushatta Berry?
Palmocarpon butlerensis Berry.
Proteoides wilcoxensis Berry.
Sophora repandifolia Berry?
Calatoloides eocenicum Berry.

The following localities in central and southwestern Texas deserve some special comment, as no collections have heretofore been made from them and they show conclusively that the Carrizo sandstone is of upper Wilcox age, but that it is in the nature of a lens which becomes thinner toward the Rio Grande, where its upper part is replaced by more typical and more argillaceous Wilcox beds that also carry characteristic fossil plants.

Fossil plants were reported by Baker from the Elmendorf clay pit, south of San Antonio, in Bexar County. This pit was not being worked in 1921 and was partly full of water, about 25 feet of grayish laminated sandy clay with local more argillaceous and darker lenses carrying leaves being all that was exposed. These leaves were poorly preserved, and the only species recognized are *Ficus mississippiensis* (Lesquereux) Berry, *Nectandra* sp., and *Sapindus linearifolius* Berry. The manager of the Elmendorf plant informed me that the clay formerly mined came from the flooded part of the pit and was full of impressions of leaves.

The Wilcox is well exposed along Nueces River in Zavalla County. Fossil plants were collected from the right bank 1 mile below the Pulliam ranch house. The following species are represented:

Anona ampla Berry.
Anona eolignitica Berry.
Cyperites sp. Hollick.
Oreodaphne obtusifolia Berry.
Sabalites grayanus Lesquereux.
Sapindus linearifolius Berry.

Sandy lenses contain many *Sabalites*, some of large size. One rachis of this species observed was 2½ inches in diameter at one end and 4 inches at the other. These species indicate a late Wilcox age and show the transgressive character of the beds, as the Midway appears to be absent on the Nueces, the Wilcox resting on the Cretaceous and not far above the conspicuous reef of *Ostrea cortex* just above the San Antonio, Uvalde & Gulf Railroad bridge.

From Story's ranch to La Pryor crossing there is a long exposure of typical Wilcox beds, especially along the left bank of the Nueces for about 2 miles above the crossing. Fossil plants are abundant but so poorly preserved that no collections were made, although several Wilcox species were recognized.

From the crossing southward the Carrizo sandstone is exposed. At an outcrop in a deep arroyo along the left bank 1½ miles south of the crossing there is an exposure of about 30 feet of buff heavily bedded and prominently cross-bedded sand. At the base of this sand 3 to 4 feet of a small brownish clay lens is visible. This lens, which is stratigraphically above the ferruginous quartzite sand exposed at the crossing, is full of leaves. The following species, which indicate upper Wilcox age, were collected:

Banksia puryearensis Berry.
Eugenia grenadensis Berry.

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Gleditsiophyllum eocenicum Berry.
Mespilodaphne coushatta Berry.
Myrcia vera Berry.
Persea longipetiolatum (Hollick) Berry.
Sabalites grayanus Lesquereux.

The type exposure of the Carrizo sandstone is in the quarries about half a mile west of Carrizo Springs, in Dimmit County. This, as well as the numerous other exposures of Carrizo and other Wilcox deposits in southwestern Texas, will be described in detail in A. C. Trowbridge's report on this region.

From the Carrizo sandstone at the type locality the following species were collected:

Acrostichum sp.
Anona ampla Berry.
Anona wilcoxiana Berry.
Canavalia eocenica Berry?
Cassia tennesseensis Berry.
Cinnamomum vera Berry?
Dryophyllum tennesseensis Berry?
Ficus mississippiensis (Lesquereux) Berry.
Nectandra pseudocoriacea Berry.
Oreodaphne obtusifolia Berry.
Oreodaphne puryearensis Berry.
Palmocarpon butlerensis Berry.
Pterobalanus texanus Berry.
Sabalites grayanus Lesquereux.
Sophora wilcoxiana Berry.
Sterculia wilcoxensis Berry.

The foregoing list represents a typical upper Wilcox flora. Fragments of leaves are not at all uncommon in the hard sandstones of the Carrizo and were observed at a considerable number of additional outcrops, but the hardness of the material rendered collecting difficult, and the coarseness of the matrix, which obliterated the venation, made the determinations inconclusive. Nowhere, however, did these fragments suggest Claiborne forms, but all were believed to represent well-known upper Wilcox species.

Near the Rio Grande the Carrizo sandstone becomes thin and is overlain by beds showing more typical Wilcox lithology. A section on Concillas Creek a quarter of a mile above its mouth, in Webb County, exposes the following materials:

Sandstone.
Brownish laminated clay with leaves.
Local unconformity.
Ripple-marked sandstone.
Clay parting.
Sandstone with sticks and leaf fragments.
Gray clay.

From the brownish clay above the local unconformity, not far below the Wilcox-Mount Selman contact, the following plants were collected:

Anacardites grevilleafolia Berry.
Banksia puryearensis Berry.
Cassia marshallensis Berry.
Cyperites sp. Hollick.
Inga wickliffensis Berry?
Juglans schimperi Lesquereux.
Mimosites variabilis Berry.
Mimusops mississippiensis Berry.
Myrica wilcoxensis Berry.
Sabalites grayanus Lesquereux.
Sophora wilcoxiana Berry.

From the sandstone two excellent specimens of *Canna eocenica* Berry were collected. The whole section is clearly upper Wilcox in age.

From Elm Creek on the Schuddemagen ranch, in eastern Uvalde County, considerably above the Cretaceous-Midway contact described by Stephenson,[2] a single specimen of *Rhamnus coushatta* Berry was collected. This is a typical upper Wilcox form and suggests that the Midway is unusually thin in this section, which is in conformity with its entire absence on the Nueces.

A systematic account of the new or noteworthy species of plants that have been added to the flora of the Wilcox group and are discussed in the present contribution is given below.

Phylum BRYOPHYTA.

Class HEPATICAE.

Order MARCHANTIALES.

Genus MARCHANTITES Brongniart.

Marchantites stephensoni Berry, n. sp.

Plate IV, figure 1.

Plant body thallose, consisting of a linear, repeatedly dichotomously forked thallus thickened medianly and with somewhat irregularly placed oblique and transverse markings, believed to represent appressed rhizoids.

The material is scanty and of slight botanic importance. Except that the margins are straighter the present form is indistinguishable from *Marchantia sezannensis* Brongniart,[3] from

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[2] Stephenson, L. W., U. S. Geol. Survey Prof. Paper 90, p. 177, 1915.

[3] Saporta, G. de, Prodrome d'une flore fossile des travertins anciens de Sézanne, p. 308, pl. 1, figs. 1-8, 1868.

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Goniopteris, of which there is a very characteristic form in the Claiborne.[6] The dryopterids are widely distributed and mainly tropical, although Christensen's subgenus *Eudryopteris*, with about 100 species, is largely confined to the North Temperate Zone.

Occurrence: Goss pit, half a mile east of Mansfield, De Soto Parish, La.; collected by O. M. Ball.

Genus ACROSTICHUM Linné.

Acrostichum sp.

This characteristic fern genus is represented in the Wilcox by a single fragment, too small for determination or description but showing the areolation of this genus. It is a strand type well represented in the Claiborne, Jackson, and Catahoula of the embayment area, and its unaccountable absence among the strand types in the Wilcox was the occasion for comment in the former discussions of this flora. The present fragment adds this interesting type to the Wilcox flora and raises the number of fern species known in this flora to eight.

Occurrence: Carrizo sandstone, half a mile west of Carrizo Springs, Dimmit County, Tex.

Phylum CONIFEROPHYTA.

Order PINALES.

Family TAXODIACEAE.

Genus CUPRESSINOXYLON Goeppert.

[Monographie der fossilen Coniferen, p. 196, 1850.]

Coniferous wood composed of tracheids and xylem parenchyma only. In the tracheid walls the pits are generally round, bordered, and isolated, in one row; if in two rows the pits stand in adjacent pairs and are not alternating or compressed. Sanio's rims often conspicuous. Normal resin canals entirely absent. Resin containing xylem parenchyma present, generally in large quantities, and scattered all through the wood. Medullary rays uniseriate; a few may be partly biseriate. The cells of the rays all alike, generally smooth-walled, and without abietinean pitting (which is present in a few species); pits in the radial walls of the rays generally circular or oval, simple, small, and in groups of one to six, seldom more, per tracheid field.[7]

Cupressinoxylon wilcoxense Berry, n. sp.

Plates I–III.

Trunks, many of them of large size, representing this species are extremely common in the upper Wilcox sands of Louisiana. They have in general suffered much from decay before silicification, but some specimens are exceedingly well preserved. They are remarkable chiefly for the great variation in the width of the zone of spring wood and the well-marked or almost complete absence of summer wood. Thus in the sections figured the zone of spring wood ranges from 5 or 6 radial rows of tracheids to 23 or 24 rows, while the summer wood consists of 3 or 4 rows. In other specimens, notably two (Nos. 206, 211) from the vicinity of Naborton, La., the spring wood consists of 45 to 70 radial rows of tracheids of uniform size separated by two rows of summer wood in which the size of the tracheids or the cell lumen is so slightly reduced that a seasonal change is scarcely marked. These woods all come from the same horizon, and their variation can not be explained by the well-known differences in the annual rings of upland and lowland forms of the same species of conifers, for it is known that the Wilcox land surface was low, the nearest uplands at that time being in the Rocky Mountain region. It is of course possible that the present species extended its range westward through Colorado and that some of these large trunks may have been brought down from the west by river floods, for at the present time Red River reaches nearly to the New Mexico boundary, and the headwaters of Arkansas River reach the foothills of the Sangre de Cristo Mountains and the Front Range in central and southern Colorado. In general the best-preserved material shows the narrower and more marked growth rings, but both types are found in all stages of decay, so that no reliable conclusions can be drawn.

Transverse section: Growth rings feebly developed or well marked, variable in width in individual specimens. Spring wood of relatively large, thin-walled, mostly isodiametric tracheids and xylem parenchyma, the two elements not distinguishable in this section, arranged in radial rows of 5 to 70 cells, averaging 10 or 12. Cell outlines round with wide lumen; diameter variable for different radial rows but in general uniform for each row, ranging from 0.025 to 0.975 millimeter. Summer wood consisting of two to four rows of somewhat reduced tracheids with narrower lumen or in some specimens scarcely reduced or narrowed and consisting of only one or two rows of cells.

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[6] Berry, E. W., Torrey Bot. Club Bull., vol. 44, pp. 331-335, pl. 22, 1917.

[7] Stopes, M. C., The Cretaceous flora: British Mus. Cat., pt. 2, p. 167, 1915.

Radial section: Tracheids with one or two rows of mostly well-spaced circular-bordered pits. When in single rows the pits are somewhat larger, and when in double rows the pits are almost invariably in pairs, although occasionally they may alternate for a short distance, as in the specimen figured; usually well-spaced occasional rows are in contact, as shown in the figure. The rims of Sanio are often prominently shown in the sections of the tangential walls. The septate xylem parenchyma is conspicuous in this section, the partitions being at right angles to the walls and from three to four times the diameter or slightly farther apart, usually containing more or less resin. The diameter of the xylem parenchyma is about the same as that of the tracheids but may be slightly greater. It is not excessively abundant, as in some other species of *Cupressinoxylon,* nor is it generally completely filled with resin. No traumatic or other resin canals are observable. Ray cells uniform in character seem to be radially elongated, with a radial length of 1½ to 2 tracheid fields and a height about one-fourth their length. End walls smooth (without abietinean pitting), mostly transverse and rarely much oblique; one or more in each ray partly resiniferous; radial walls with two small oval pits per tracheid field; these pits are relatively large for this genus and appear to have their long axis uniformly inclined about 40° from the vertical.

Tangential section: The distribution and relative abundance and variation in the rays are well shown in the figure of a large area under low magnification (20 diameters). The rays are uniformly uniseriate, of relatively large, thin-walled, roundish quadrangular cells, one or more of which may be resiniferous; they range in height from 2 to 17 cells and consist prevailingly of alternations of rays 2 to 4 cells high with those of rays 6 to 8 cells high. There are rarely four rows of tracheids between adjacent rays, the normal number being two. The xylem parenchyma, as in the radial sections, is generally bordered by rays. The angential walls of the tracheids are marked with circular-bordered pits about one-half the ize of the pits on the radial walls. These pits are usually in a single row and well spaced, but they may be in juxtaposition for a short distance or in double rows, either in pairs or alternating for short distances, as shown in the enlarged figure. In this section the rotted and spirally fractured walls of the tracheids are very obvious, and care is necessary to distinguish them when in this condition from normal spirally thickened tracheids, which are not present in this genus. In this section the cross sections of the bordered pits of the radial walls of the tracheids often come out beautifully, and they can even be seen in the figure enlarged but 20 times.

This well-marked species is perfectly distinct from *Cupressinoxylon calli,* described by Knowlton[8] from material collected in beds of possible Wilcox age in Arkansas. It also appears to be unlike the rather numerous described species of *Cupressinoxylon* from other horizons or areas. The incompleteness of large numbers of the descriptions of previously known forms renders detailed comparisons futile. The distinction between the present species and those forms of fossil wood referred to the genus *Podocarpoxylon* Gothan, as amended by Stopes[9] to include Gothan's *Podocarpoxylon* and *Phyllocladoxylon,* are not especially obvious and rest on the size, form, and number of the pits on the radial walls of the ray cells, which are larger, fewer, and more eccentric in *Podocarpoxylon.* More recently Seward[10] has proposed the form genus *Mesembrioxylon* for these. These differences are all relative and hardly generic in character, as a series of species can be selected which connect the extremes.

In the present state of our knowledge of wood anatomy, even among the comparatively well known group of conifers, it is not feasible to attempt to point out the most closely allied existing representative of the present species.

The genera *Glyptostrobus* and *Taxodium* are represented by foliage and seeds in the Wilcox, and it may well be that this abundant wood type represents one or the other of these genera.

Occurrence: Caddo and De Soto parishes, La. Figured specimens, northwest corner sec.

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[8] Knowlton, F. H., Arkansas State Geologist Ann. Rept. for 1889, vol. 2, p. 254, pl. 9, figs. 3-7, 1891.

[9] Stopes, M. C., The Cretaceous flora: British Mus. Cat., pt. 2, p. 210, 1915.

[10] Seward, A. C., Fossil plants, vol. 4, p. 173, 1919.

36, a quarter of a mile south of Slaughter Pen Bluff, Caddo Lake (201); Shreveport (210, 269). Other specimens, Slaughter Pen Bluff, Caddo Lake (203); 6 miles southeast of Naborton (205, 206); 4½ miles southeast of Naborton (216); 4 miles southeast of Naborton (208); 3 miles southeast of Naborton (209, 211); 2¼ miles southeast of Naborton (204); 1 mile southeast of Naborton (268); half a mile southeast of Naborton (213); 6 miles southeast of Mansfield (270); 1½ miles north of Mansfield (266).

Phylum ANGIOSPERMOPHYTA.

Class MONOCOTYLEDONAE.

Order ARECALES.

Family ARECACEAE.

Genus PALMOCARPON Lesquereux.

Palmocarpon butlerensis Berry, n. sp.

Plate IV, figures 2–4.

Fruit apparently a small, thin-fleshed drupe, in form a prolate spheroid—the long diameter less than one-half greater than the short diameter. Varying considerably in size. Surface of the stone dark in color (possibly a secondary feature), conspicuously papillose. Hilum large. Minimum dimensions 4 by 5 millimeters; maximum 14 by 18 millimeters. Abundant but generally slightly deformed. Specific name in allusion to the name of the salt dome from which the material was collected.

This form is very similar to *Palmocarpon truncatum*, from Golden, Colo., described by Lesquereux in 1878 and supposed to have come from the Denver formation. There is the same variation in size in both, and although Lesquereux makes the flattening of the Golden specimens a specific character this is of doubtful validity, as he states that the specimens were generally crushed. I would have referred these Wilcox fruits to *Palmocarpon truncatum* except for the definite and repeated statement by Lesquereux that the Golden form was smooth, which the Wilcox form is not. In any event the two are closely related. Lesquereux[11] compared the Golden forms with the fruits of the existing *Sabal mexicana* Martius, and similarly the Wilcox fruits may be those of *Sabal*. Leaves of *Sabalites grayanus* Lesquereux are widespread in the Wilcox, but they are not conclusively known to be related to *Sabal*. Moreover, very many modern palms have racemes of small fruits very similar to the present fossils. To mention but a few familiar existing species with fruits very close to the fossil I may cite our dwarf saw palmetto, *Serenoa serrulata* (Michaux) Hooker; the royal palm, *Roystonea regia* (H. B. K.) Cook; the goose-neck palmetto, *Sabal etonia* Swingle; and the cabbage palmetto, *Sabal palmetto* (Walter) Roemer and Schultes.

Occurrence: Butler salt dome, 6 miles northeast of Oakville, Freestone County, Tex.; 4 miles southwest of Boydsville, Ark.; Carrizo sandstone half a mile west of Carrizo Springs, Dimmit County, Tex.

Class DICOTYLEDONAE.

Order URTICALES.

Family MORACEAE.

Genus ARTOCARPOIDES Saporta.

Artocarpoides balli Barry, n. sp.

Plate IV, figures 8–10; Plate V.

Leaves of variable size, ovate, with a broadly rounded base, which is sometimes slightly inequilateral, and a narrowed and apiculate tip. Margins entire, slightly undulate. Texture subcoriaceous. Petiole invariably missing. Midrib stout, very prominent on the lower surface of the leaf. Secondaries stout and prominent, 9 to 15 pairs, opposite to alternate, approximately equally spaced and subparallel, the basal one or two pairs at right angles to the midrib, becoming regularly more ascending toward the upper part of the leaf, relatively straight at first, becoming curved in the marginal region and eventually camptodrome close to the margins. Tertiaries well marked, closely spaced, percurrent. Areolation well marked, quadrangular.

The smallest leaves referred to this species are only 4 centimeters in length and 2 centimeters in maximum width; the largest is 24 centimeters in length and 10 centimeters in maximum width. There are six specimens of various sizes in the collection, and all preserve their specific features unchanged. The type is well marked and clearly different from previously described members of the Wilcox flora. A species from Puryear, Tenn., was described as *Artocarpoides wilcoxensis*.[12] This was more elliptical in outline, widest medianly and pointed at both ends, with fewer, thinner secondaries, less closely set tertiaries, and more open areolation.

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[11] Lesquereux, Leo, The Tertiary flora: U. S. Geol. Survey Terr. Rept., vol. 7, p. 120, pl. 11, figs. 6–9, 1878.

The genus *Artocarpoides* was founded by Saporta for certain forms from the Paleocene of Sézanne, France, that he compared with the existing entire-leafed species of *Artocarpus*, which they really greatly resemble. Schenk [13] considered them to be related to the Juglandaceae, but I fail to see any basis for this comparison. Among the French forms a considerable resemblance to the present species is shown by *Artocarpoides conocephaloidea* Saporta,[14] a relatively small form, and a very great resemblance by *Protoficus sezannensis* Saporta[15] and *P. insignis* Saporta.[16] Among existing forms of Moraceae considerable resemblance is also shown by the tropical American genus *Brosimum* Swartz, which ranges from the West Indies and Central America to Brazil, and the tropical American genus *Coussapoa* Aublet, which has about 15 existing species with a similar range and which is found fossil in the Tertiary of Venezuela, southern Mexico (Miocene and Pliocene), and Bolivia. For example, the present species resembles a tropical American leaf figured by Ettingshausen and called *Artocarpus rigida* Linné. Whether Ettingshausen confused the oriental *Artocarpus rigida* of Blume or whether his leaf was an American species of *Coussapoa* or some related genus I do not know, nor is it material, for in any case the resemblance between the fossil and certain recent Moraceae is emphasized.

It is possible that these Wilcox forms are more closely related to these last-named genera than they are to *Artocarpus*, but they are surely referable to the Moraceae.

The present species is named for the collector, Prof. O. M. Ball.

Occurrence: Goss pit, half a mile east of Mansfield, De Soto Parish, La.; collected by O. M. Ball.

Genus FICUS LINNÉ.

Ficus mississippiensis (Lesquereux) Berry.

Plates VI, VII, and VIII.

Cinnamomum mississippiensis Lesquereux, in Dana, Manual of geology, 1st ed., p. 513, fig. 794, 1866; Am. Philos. Soc. Trans., vol. 13, p. 418, pl. 19, fig. 2, 1869.

Knowlton, Am. Geologist, vol. 16, p. 308, 1895; U. S. Geol. Survey Prof. Paper 101, p. 320, pl. 89, fig. 2, 1917.

Berry, U. S. Geol. Survey Prof. Paper 91, p. 298, pl. 37, fig. 2, 1916.

Ficus planicostata Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1872, p. 393, 1873; Tertiary flora, p. 201, pl. 31, figs. 1-8, 10-12, 1878.

?Newberry, U. S. Geol. Survey Mon. 35, p. 88, pl. 46, fig. 1, 1898.

Cockerell, Colorado Univ. Studies, vol. 7, p. 151, 1910.

Ficus clintoni Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1872, p. 393, 1873.

Ficus planicostata goldiana Lesquereux, idem for 1873, p. 399, 1874; Tertiary flora, p. 202, pl. 33, figs. 1-3, 1878.

Ficus pseudopopulus Lesquereux, U. S. Geol. and Geog. Survey Terr. Bull., vol. 1, p. 387, 1875; idem, Ann. Rept. for 1874, p. 313, 1876; Tertiary flora, p. 204, pl 34, figs. 1a, 2.

Berry, U. S. Geol. Survey Prof. Paper 91, p. 200, pl. 37, figs. 3-5; pl. 113, fig. 3, 1916.

Knowlton, U. S. Geol. Survey Prof. Paper 101, p. 304, pl. 72, figs. 2-4; pl. 73, figs. 1, 2; pl. 112, fig. 3, 1918.

Ficus occidentalis (Lesquereux) Lesquereux, Tertiary flora, p. 200, pl. 32, fig. 4, 1878; Mus. Comp. Zool. Bull., vol. 16, p. 50, 1888.

Penhallow, Report on Tertiary plants of British Columbia, p. 55, 1908.

Berry, U. S. Geol. Survey Prof. Paper 91, pp. 121, 197, pl. 28, fig. 3, 1916.

Knowlton, U. S. Geol. Survey Prof. Paper 101, p. 331, pl. 72, fig. 1, 1918.

Dombeyopsis occidentalis Lesquereux, U. S. Geol. and Geol. Survey Terr. Ann. Rept. for 1872, p. 380, 1873.

Ficus planicostata clintoni Knowlton, U. S. Geol. Survey Bull. 152, p. 103, 1898; U. S. Geol. Survey Prof. Paper 191, p. 303, pl. 76, fig. 3, 1918.

Ficus planicostata latifolia Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1872, p. 393, 1873; Tertiary flora, p. 202, pl. 31, fig. 9, 1878.

Berry, U. S. Geol. Survey Prof. Paper 91, p. 199, 1916.

Ficus latifolia Knowlton (not Kunth, 1846), U. S. Geol. Survey Bull. 152, p. 102, 1898; U. S. Geol. Survey Prof. Paper 101, p. 304, 1917.

Ficus cockerelli Knowlton, U. S. Geol. Survey Bull. 696, p. 273, 1919.

Ficus planicostata maxima Berry, U. S. Geol. Survey Prof. Paper 91, p. 199, pl. 34, fig. 3, 1916.

Ficus planicostata Lesquereux. Hollick, Louisiana Geol. Survey Special Rept., p. 282, pl. 36, 1888.

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[12] **Berry, E. W.**, U. S. Geol. Survey Prof. Paper 91, p. 194, pl. 109, fig. 5, 1916.

[13] **Schenk, August**, Palaeophytologie, pp. 451, 477, 1890.

[14] **Saporta, G. de**, op. cit., p. 68, pl. 7, fig. 6, 1868.

[15] Idem, p. 67, pl. 6, fig. 1.

[16] Idem, p. 68, pl. 6, figs. 2-4.

Ficus neoplanicostata Knowlton, U. S. Geol. Survey Prof. Paper 101, p. 303, pl. 73, fig. 4; pl. 74, figs. 2, 3; pl. 76, fig. 4, 1918.
Berry, U. S. Geol. Survey Prof. Paper 91, p. 198, pl. 114, fig. 1, 1916.
Ficus richardsoni Knowlton, U. S. Geol. Survey Prof. Paper 101, p. 305, pl. 76, fig. 1, 1918.

It would seem that if the systematic work of paleobotany is to be made available for the general purposes of geology and botany the paleobotanist must take the time to coordinate and digest the results of the work on local floras. There are certain general principles that should guide workers in founding new species, and I am thoroughly in accord with the principle which holds that analysis should precede synthesis, and that in describing specimens from a new horizon or a remote geographic locality the presumption should prevail that they are distinct from previously described forms unless identity can be conclusively shown. Likewise there are certain forms in a different category, long known and hence not susceptible of this treatment—for example, *Podozamites lanceolatus*, *Asplenium dicksonianum*, or *Sequoia reichenbachi*—which are obviously composite and yet which do not offer any criteria for segregation other than those of a stratigraphic nature. These forms may well remain as they are until the progress of knowledge enables the paleobotanist to treat them in a scientific manner.

In a recent study of a large and well-preserved collection from the Wilcox near Mansfield, La., I have been profoundly impressed with the graded variability in the leaves of certain genera, particularly *Ficus* and *Rhamnus*. In my report on the flora of the Wilcox group, published in 1916, 18 different species of *Ficus* were recognized, and in Knowlton's recently published report on the flora of the Raton formation 17 species of *Ficus* are recognized. In both works the comparisons made appear legitimate, but in neither, apparently, had the broader question of interrelationship in the genus received adequate consideration. To revert to the representation of *Ficus* in the Wilcox flora: Of the 18 identified forms a reexamination appears to confirm the validity of 13 beyond question. The remaining five species, which were identified as *Ficus neoplanicostata*, *pseudopopulus*, *planicostata maxima*, *occidentalis*, and *denveriana*, represent ovate types with three basilar or subbasilar primaries and percurrent tertiaries. As sparingly represented in the original collections each showed a certain individuality, but in the later collection, where they are abundant, they show every gradation in size and in the ratio of width to length.

I do not consider it possible to maintain specific boundaries in this series, although the extremes of size or of short-elliptical or long and narrow ovate-acuminate outline are strikingly different in aspect.

This polymorphism, or better termed variability, led to the assembling of all the published figures of the so-called species enumerated in the foregoing synonymy. It was found that these forms had been described at different times by different workers and that the criteria of separation were as follows:

1. Size.
2. Relative proportions of width to length.
3. Shortening or lengthening of the apex.
4. Character of base ranging from various degrees of cuneate through truncate to slightly cordate.
5. Number and spacing of the secondaries.
6. Position of the primaries, whether basilar, subbasilar, or suprabasilar.

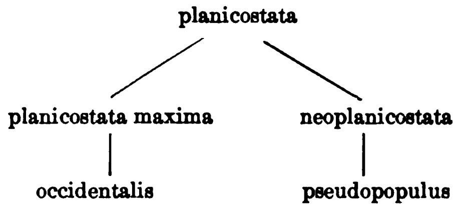
In all the species the general facies and tertiary venation remain identical throughout. It might be argued that these represent generic features and that the foregoing criteria of separation are legitimate specific features. It may be noted, however, that most of the features enumerated above are interrelated and dependent upon the proportions of the leaves, and it may also be noted that leaves which are normally large at maturity reach that normal size by growth, so that mere smallness is not a specific character. However, I will not quarrel with my colleagues who prefer to keep the species listed in the foregoing synonymy distinct—the relationships sketched below hold good, whatever categories are used. Some will doubtless incline to consider them varieties of a single botanic species, but I can only think of them as varieties in the praenuntial or formative state, with the intermediate steps not yet extinct, and it seems to me that all could probably have been found on a single lower Eocene tree. Were they ever found unassociated there might be some justification for maintaining their distinctness, but wherever adequate collections are available, whether it be from the Denver formation, the Raton formation, or the Wilcox group, all or nearly all the forms are found associated in the same stratum. Fifteen to twenty species of a single genus do not grow together in nature.

If these forms are considered to represent a single variable species, then the earliest name available is *mississippiensis*, given by Lesquereux to what he regarded as a species of *Cinnamomum*. It is true that this form was rather small in size, but the type is no longer in existence and the later material identified as this species is larger. For example, the form so named in the Raton flora is identical with the associated forms referred to *Ficus pseudopopulus*. The type of this last-mentioned species was also based on small forms, which do not, however, differ in any essential respect from the larger leaves later determined, and the maximum of size and elongation is furnished by the forms from the Wilcox figured in the present contribution. I have not included *Ficus denveriana* in the foregoing synonymy, as it prevailingly lacks the three primaries and is pinnate veined. However, certain specimens so called appear to belong here, as, for example, the specimen shown in figure 5 on Plate XXXIII of Lesquereux's "Tertiary flora."

Ficus planicostata Lesquereux represents variants with a foreshortened apex, although the smaller leaves of this so-called species as figured by Lesquereux are indistinguishable from the small leaves of *Ficus neoplanicostata* figured by Knowlton.

If the central stock of this variable species is considered to have been an elliptical-ovate penniveined form similar to the typical *Ficus denveriana* Cockerell or to the young leaves referred to *Ficus neoplanicostata*, then the assumption of the specific character of *Ficus mississippiensis* would be the transformation of the basal secondaries into lateral primaries. As triveined forms of *Ficus* are not uncommon in the Upper Cretaceous the ancestral stock of *Ficus mississippiensis* may go back to some such form as *Ficus ovatifolia* Berry, of the Coastal Plain Cretaceous, or *Ficus praetrinervis* Knowlton, of the Vermejo formation, and *Ficus denveriana* may be unrelated or else represent the transformation of lateral primaries into basal secondaries.

Discussion may be eliminated by presenting the supposed interrelationship diagrammatically in terms of the specific names of the above synonymy, as follows:



The maxima of these two lines of variation are shown in the accompanying figures, and no detailed description of them is regarded as necessary. A statement regarding the recorded geographic and geologic range of the species may not, however, be out of place. This may be presented in tabular form, as follows:

	Laramie.	Wilcox.	Raton.	Post-Laramie, Black Buttes coal group, or Evanston.	Clarno.	Denver.
Cinnamomum mississippiensis		×	×			
Ficus planicostata	×	(?)	×	×	(?)	×
Ficus pseudopopulus		×	×	×		
Ficus occidentalis		×	×			×
Ficus planicostata maxima		×	×			
Ficus neoplanicostata		×	×			
Ficus richardsoni			×			

It may be noted that only one of these species, namely, *F. planicostata*, is recorded from a pre-Tertiary horizon, and that all are found associated in both the Wilcox and Raton floras, *Ficus richardsoni* Knowlton of the Raton not being an exception to this statement, for it is obviously identical with *Ficus pseudopopulus*. Occurrences in the Wilcox range throughout the group and are as follows:

Ackerman formation: Raglans Branch, Lafayette County, Miss.; Colemans Mill, Choctaw County, Miss.; Hurleys, Benton County, Miss.

Upper Wilcox: Shreveport, Caddo Parish, La.; Mansfield, Naborton and vicinity, De Soto Parish, La.; Old Port Caddo Landing, Harrison County, Tex.; Elmendorf clay pit, Elmendorf, Bexar County, Tex.; Carrizo sandstone half a mile west of Carrizo Springs, Dimmit County, Tex.

Lagrange formation (middle and upper Wilcox age): Puryear, Henry County, Tenn.; Sandy, Hardeman County, Tenn.

Order RANALES.

Family MAGNOLIACEAE.

Genus MAGNOLIA Linné.

Magnolia angustifolia Newberry.

Plate IX.

Magnolia angustifolia Newberry, U. S. Nat. Mus. Proc., vol. 5, p. 513, 1882.
Berry, U. S. Geol. Survey Prof. Paper 91, p. 214, 1916.
Knowlton, U. S. Geol. Survey Prof. Paper 101, p. 309, pl. 79, fig. 1; pl. 80; pl. 81, fig. 1, 1917.
Magnolia attenuata Weber. Lesquereux, Tertiary flora, p. 250, pl. 45, fig. 6, 1878.
Terminalia radobojensis Heer (not Unger). Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1871, Suppl., p. 15, 1872.
Magnolia lanceolata Lesquereux. Hollick, Louisiana Geol. Survey Special Rept. 5, p. 282, pl. ii, 1899.

This species, which is common in the Raton formation and in the upper part of the Wilcox group, is much more common west of the Mississippi than east of it. A specimen from Louisiana is figured in the present paper.

Occurrence: Goss pit, half a mile east of Mansfield, De Soto Parish, La.; collected by O. M. Ball.

Magnolia leei Knowlton.

Plate X.

Magnolia leei Knowlton MS. Berry, U. S. Geol. Survey Prof. Paper 91, p. 215, pl. 43, figs. 1, 2, 1916.
Knowlton, U. S. Geol. Survey Prof. Paper 101, p. 313, pl. 64, fig. 2; pl. 65, fig. 2; pl. 81, fig. 2, 1918.

This well-marked species, which is abundant in the Raton formation in Colorado and New Mexico, appears to range from the bottom to the top of the Wilcox group in the embayment region. It has not heretofore been found in that region west of the Mississippi but proves to be not uncommon in Louisiana.

Occurrence: Goss pit, half a mile east of Mansfield, De Soto Parish, La.; collected by O. M. Ball.

Family MENISPERMACEAE.

Genus MENISPERMITES Lesquereux.

Menispermites cebatholdes Berry, n. sp.

Plate XI, figure 1.

Leaves orbicular-ovate, about as wide as long, with a wide truncate base and a broadly and shortly pointed apex. Margins entire. Texture thin. Length about 10 centimeters; maximum width, below the middle, about 10 centimeters. Petiole missing, but from the character of the base it must have been of considerable length and expanded where it joined the lamina; the joint was at an angle with the plane of the lamina. There are 7 primaries from the widely expanded apex of the petiole at the extreme base of the leaf. These diverge at acute regularly spaced angles; all are curved, and the midrib is slightly, if at all, stouter than the lateral primaries. It is longer, however, and at about one-third of its distance to the apex it gives off, at acute angles, a pair of opposite secondaries, which sweep upward and are camptodrome in the tip of the leaf. The lateral primaries are all stout and prominent and decrease in length from above downward. The basal, shortest, and straightest pair form angles of about 70° with the midrib; they give off on the outside three or four regularly spaced secondaries, which are camptodrome close to the margin; the tip joins the tip of the basal secondary of the primary next above by a simple camptodrome arch close to the margin. The second pair of primaries form angles of about 50° with the midrib; they are longer and slightly stouter than the basal pair and slightly more curved, but less so than the third pair of primaries; they give off on the outside two to four regularly spaced stout secondaries which are camptodrome close to the margin; their tip joins a simple camptodrome tertiary from the lowest secondary of the third primary by a simple camptodrome curve close to the margin. The third pair of primaries form angles of about 25° with the midrib; they are more curved than the others and give off on the outside four or five regularly spaced secondaries, which are simply camptodrome close to the margins and the basal one of which may have the caliber and appearance of a dichotomous fork of the primary, as in the left side of the leaf figured; the tip of the third primary rves close to the margin to join a camptodrome tertiary from the outside of the main air of secondaries from the midrib. The tertiaries, with the exception of the camptodrome nes already alluded to, are thin and largely mersed, exceedingly regular in their spacing, nd prevailingly percurrent, although they ocsionally fork and inosculate, as shown in the gured specimen. The ultimate areolation is airly distinct in spots and must have been ntirely so in life; it shows relatively large and revailing subrectangular meshes.

This fine species is obviously new and forms striking addition to the Wilcox flora, as its odern relatives are all climbing or twining erbs or shrubs prevailingly of wooded or ream-side habitats. It is similar in form to e Wilcox species *Cercis wilcoxiana* Berry but ntirely different in its venation characters and bviously not related to that form. The pre- iously known Wilcox species of *Menispermites*, *I. wilcoxensis* Berry, is a much more typically vate form with a prolonged acuminate tip and ut three instead of seven primaries. The ertiary venation and the camptodrome arches lose to the margins are the same in both, and either shows the tendency toward a lobation f the lamina, which is so pronounced a feature n so many of the existing species of this mily.

The existing species are too imperfectly nown and polymorphous to render detailed mparisons with this Eocene form of much alue. The fossil is not unlike the leaves of ur common *Menispermum canadense* Linné, hich are nonlobate. It shows a similar semblance to the leaves of our common *ebatha carolina* (Linné) Britton, which are onlobate, and similar statements might be ade with regard to a large number of exist- g species of the family. Among fossil forms e most similar is *Cocculus* (*Cebatha*) *latifolius*, om the Pliocene of France, described by aporta and Marion,[17] but this similarity is f the same order as the comparisons with ecent forms just mentioned.

The polymorphism of the existing species enders it desirable to refer this new form to the enus *Menispermites*, implying a fossil form of enispermaceae of undeterminable generic ffinity. It might very well be ancestral to the genus *Cocculus* De Candolle, or *Cebatha* Forskal, as modern taxonomists prefer to call it, as Forskal's name was published in 1775, or 43 years earlier than De Candolle's proposal.

The existing species of Menispermaceae number about 350 in about 60 genera. All are twining or climbing woody or herbaceous plants with alternate exstipulate leaves and drupaceous fruits. A majority of the species are confined to moist tropical regions, but a considerable number are found in both temperate zones. None of the subfamilies are confined to a single continental region, and several of the genera are found on all the continents.

The existing species of *Menispermum*, but two or three in number, are confined to Atlantic North America and eastern Asia, which indicates a wider range during geologic time. The genus *Cebatha* (*Cocculus*) is a large one for this family, with about 30 species, its distribution including all the continents except Europe and extending to the Hawaiian Islands. Several fossil species that have been referred directly to it or to the form genus *Cocculites* go back as far as the Upper Cretaceous. A well-marked species is present in the later Tertiary of the Mississippi embayment, and it would perhaps not be far from the truth if the present species were referred to this genus.

The family has 10 genera with about 75 species confined to the Western Hemisphere, mostly in tropical South America. Asia has 13 peculiar genera; Africa, including Madagascar, has 14; and Australia has 7, all monotypic and largely found in the peculiar environment of Western Australia. The largest number of existing species occur in tropical Asia, from which about 150 are known, or about 50 more than are known from America, which ranks second in the number of existing forms.

The fossils of the narrow triveined form of some species of *Cocculus* (*Cebatha*) are rather difficult to determine, for they show more or less resemblance to some leaves in the families Smilacaceae, Lauraceae, Urticaceae, Piperaceae, Melastomataceae, and others.

The wider leaves are more characteristic, and species of *Menispermum* are recorded from beds as early as the Oligocene of France. The form genus *Menispermites* has numerous Upper Cretaceous species, particularly of Cenomanian and Turonian age, and is recorded from Portugal, Bohemia, Greenland, Argentina, and various localities in the United States and Canada. It is especially varied in the Dakota sandstone.

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[17] Saporta, G. de, and Marion, A. F., Recherches sur les végétaux ssiles de Meximieux, p. 264, pl. 31, figs. 4-7; pl. 32, fig. 1, 1876.

Forms referred to *Cocculus* De Candolle, *Cocculites* Heer, or *Cebatha* Forskal are recorded from the Upper Cretaceous of North America, Europe, and Asia and from the early Tertiary of Greenland, North America, and Europe. It seems probable that some of the forms referred to Unger's genus *Daphnogene* belong to this family. The genus *Macclintockia* Heer, of the Upper Cretaceous and early Tertiary, particularly of the Arctic region, is often referred to this family, as by Schimper.

Occurrence: Goss pit, half a mile east of Mansfield, De Soto Parish, La.; collected by O. M. Ball.

Order ROSALES.

Family CAESALPINIACEAE.

Genus CASSIA Linne.

Cassia emarginata Berry.

Cassia emarginata Berry, U. S. Geol. Survey Prof. Paper 91, p. 233, pl. 45, fig. 17b; pl. 48, fig. 5, 1916.

Heer[18] mentions a *Cassia emarginata* of Saporta, which would, if valid, necessitate changing the name of this Wilcox species. As near as I can discover, however, *Cassia emarginata* Saporta was a nomen nudum. It is not mentioned by either Schimper or Schenk, and Saporta appears to have renamed the form *Caesalpinites latifolius* when he actually described it.[19]

Family MIMOSACEAE.

Genus MIMOSITES Bowerbank.

Mimosites variabilis Berry.

Mimosites variabilis Berry, U. S. Geol. Survey Prof. Paper 91, p. 227, pl. 45, figs. 6–11, 1916.

This common middle and upper Wilcox species has not heretofore been found south of Grenada, Miss. It is contained in recent collections from a locality 1 mile west of Clayhatchee, Dale County, Ala.

Family PAPILIONACEAE.

Genus DALBERGIA Linné fils.

Dalbergia puryearensis Berry, new name.

Dalbergia eocenica Berry, U. S. Geol. Survey Prof. Paper 91, p. 245, pl. 53, figs. 1, 2, 1916.

The name assigned to this Wilcox *Dalbergia* in 1916 is antedated by *Dalbergia eocenica* Ettingshausen,[20] based on *Protamyris eocenica* Unger,[21] and I therefore propose that this species be called *Dalbergia puryearensis*, in allusion to the type locality.

Order SAPINDALES.

Family ICACINACEAE.

Genus CALATOLOIDES Berry, n. gen.

Calatoloides eocenicum Berry, n. sp.

Plate XIV, figures 3–5.

The present species is based on casts of a nutlike fruit which appears to be very close to those of a recently described genus that is referred with some doubt to the family Icacinaceae and is based upon three new species of existing arborescent forms of the Central American region. In view of the incompleteness of the fossil material and the lack of certainty as to its identity with the recent fruits in all particulars, it has seemed best to propose a new genus for its reception. The name suggested for this new genus implies a relationship with the existing genus. The fossil fruit as restored from casts is a moderately prolate spheroid, 2.5 to 3 centimeters in length and about 2.25 centimeters in diameter, broadly rounded proximad and bluntly pointed distad. The ligneous shell is marked by somewhat irregular prominent branching and anastomosing longitudinal ridges, connected by low subordinate irregularly transverse ridges. If it was like the existing form it contained a single large seed.

I have had this Wilcox material in my possession for a number of years without any idea as to its botanic relationship. In collecting recent fruits in Panama in 1919 I obtained one which suggested the fossil. In seeking to determine the Panama specimen at the United

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[18] Recherches sur le climat et la végétation du pays tertiaire, p. 149, 1861.

[19] Saporta, G. de, Etudes sur la végétation du sud-est de la France à l'époque tertiaire, vol. 1, p. 140, 1863.

[20] Ettingshausen, Constantin, Beiträge zur Kenntniss der fossilen Flora von Sotzka, p. 73, 1858.

[21] Unger, Franz, Die fossile Flora von Sotzka, p. 180, pl. 31, fig. 15, 1850.

States National Herbarium I found that it was identical with material from Costa Rica which Messrs. Standley and Safford considered to represent a new genus, very probably a member of the Icacinaceae. They have since recognized three species of this genus—two from Mexico and one from Costa Rica and Panama. These are trees of considerable size, with broadly lanceolate camptodrome-veined leaves. The fruits have a thin flesh in life and a single large spherical seed. The fossil form is similar in shape and ornamentation but is only about half the size of the recent fruits and may therefore be considered as standing in an ancestral relation to the modern genus, for which Standley and Safford have proposed the name *Calatola*.

The occurrence of a fossil representative of the family Icacinaceae in the lower Eocene of Texas is of very great interest. No member of the family, so far as I know, has ever before been found fossil. The family consists of about 39 genera and 150 existing species, of which only 8 genera, with less than 30 species, are found in America, where they are for the most part confined to the Tropics. None of these genera except *Mappia*, a native of the Antilles, occurs in any other geographic region, and this genus is supposed to be represented in Ceylon and farther India. As the forms from farther India constitute the subgenus *Trichocrater* and those from Ceylon the subgenus *Eumappia*, it seems doubtful if *Mappia* is really an exception to the peculiar character of the existing American members of this family. The family as a whole is distinctly oriental in the existing flora, with its center of dispersal in the south Asian region, for although there is only a single monotypic genus confined to southeastern Asia, this region pairs with Africa, the East Indies, or Australia in many occurrences: thus there are 8 genera with 23 species which are Malaysian, 6 genera with 34 species which are Asian and Malaysian, 3 genera with 19 species which are common to Africa and southern Asia, and 1 genus with 4 species common to Malaysia and Australia. Ten genera with 33 species are confined to Africa, and 3 genera with 6 species are confined to Australia.

The family contains 10 monotypic genera—one of Guiana and all the remainder Old World forms, as follows: Africa 3, southeastern Asia 1, East Indies 2, New Guinea 1, New Caledonia 2. All the existing American forms belong to the large subfamily Icacinoideae, which is also represented in all the other regions, so that its origin or interrelationships are unknown.

Occurrence: Butler (West Point) salt dome, in the eastern part of Freestone County, near Trinity River, 6 miles northeast of Oakville, Tex.; collected by O. B. Hopkins and O. C. Funderbunk.

Order RHAMNALES.

Family RHAMNACEAE.

Genus RHAMNUS Linné.

Rhamnus cleburni Lesquereux.

Rhamnus cleburni Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1872, p. 381, 1873; Tertiary flora, p. 280, pl. 53, figs. 1–3, 1878; U. S. Nat. Mus. Proc., vol. 11, p. 24, 1888.

Knowlton, U. S. Geol. Survey Bull. 204, p. 80, 1902.

Berry, U. S. Geol. Survey Prof. Paper 91, p. 283, 1916.

The present material, which is abundant, emphasizes the great similarity and possible identity between this form and *Rhamnus coushatta* Berry,[22] also the great variability in outline of these leaves, many of which are longer and relatively narrower than the type and show indications of grading into what I have called *Rhamnus marginatus apiculatus*.[23]

Occurrence: Goss pit, half a mile east of Mansfield, De Soto Parish, La.; collected by O. M. Ball.

Rhamnus marginatus apiculatus Berry.

Plate XI, figures 2, 3.

Rhamnus marginatus apiculatus Berry, U. S. Geol. Survey Prof. Paper 91, p. 283, pl. 69, fig. 1, 1916.

At the time of the publication of the report on the Wilcox flora this variety was represented by a small number of specimens from the Ackerman formation of Mississippi. It is common in later collections from Louisiana and shows considerable variation in size and outline. All the specimens are somewhat narrower than the type; some have a very long acumen and others lack a prominent acumen. Two of these specimens are figured, the larger a leaf 21 centimeters in length and 4 centimeters in maximum width.

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[22] Berry, E. W., U. S. Geol. Survey Prof. Paper 91, p. 284, pl. 68, fig. 1, 1916.

[23] Idem, p. 283, pl. 69, fig. 1.

Occurrence: Goss pit, half a mile east of Mansfield, De Soto Parish, La.; collected by O. M. Ball.

Genus RHAMNITES Forbes.

Rhamnites knowltoni Berry, new name.

Plate XII, figure 7.

Cornus studeri Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1871, p. 293, 1872 (not Heer, 1859); Tertiary flora, p. 244, pl. 42, figs. 4, 5, 1878.

Hollick, in Harris and Veatch, A preliminary report on the geology of Louisiana, p. 286, pl. 45, fig. 2, 1899.

Knowlton, U. S. Geol. Survey Bull. 163, p. 68, pl. 15, fig. 3, 1900.

Berry, U. S. Geol. Survey Prof. Paper 91, p. 331, pl. 68, fig. 3, 1916.

In the account of the Wilcox flora this species was said to be represented by fragments from a number of localities, the most complete specimen being the one figured from Coushatta, La. Subsequent collections show that this form is abundant in the Wilcox near Mansfield and confirm the previous statement that it differs from Heer's Swiss Miocene type and also is not properly referable to the genus *Cornus*. Although in some of the features it is similar to species that have been referred to *Ficus*, these features are not like any in existing forms of that genus, where the venation has certain characteristics that are easily recognized. They are, on the other hand, characteristic of certain members of the families Sapindaceae and Rhamnaceae, particularly the latter, and I have therefore transferred the American forms to the genus *Rhamnites*.

R. knowltoni may be described as follows:

Leaves large, broadly ovate, many of them slightly inequilateral, the tip somewhat narrowed and acuminate and the base rounded or very broadly pointed. Margins entire, in some specimens faintly undulate. Texture subcoriaceous. Midrib stout and prominent. Secondaries stout, six to nine pairs, diverge from the midrib at irregular intervals at angles of about 45°, camptodrome. Tertiaries thin, closely spaced, percurrent, typically rhamnaceous. Size variable, some leaves being as much as 19 centimeters in length and 9.5 centimeters in maximum width, which is in the lower half of the leaf. A large specimen from Mansfield is figured in the present paper. The single Louisiana specimen has a length of 16 centimeters and a maximum width, midway between the apex and the base, of 8.75 centimeters.

Occurrence: Goss pit, half a mile east of Mansfield, De Soto Parish, La.; collected by O. M. Ball.

Order MALVALES.

Family MALVACEAE?

Genus MONOCARPELLITES Perkins.

[Vermont State Geologist Rept. for 1903-4, p. 180.]

Monocarpellites perkinsi Berry, n. sp.

Plate XII, figures 1-6.

Ligneous single-celled carpels, with numerous seeds. General form spheroidal; whether oblate or prolate is uncertain, as the material has suffered much compression. Probably nearly spheroidal in life, with 10 to 12 thin longitudinal ribs. Apex mucronate-tipped. Hilum large depressed, about 2 millimeters in diameter.

This species is not uncommon at the locality cited, but it is impossible to determine the character of the interior. The conclusion that the ribs do not represent keels or sutures of a tardily dehiscent capsule rests upon their somewhat unequal spacing, the lack of any traces of sutures, and the fact that one specimen has undergone great compression in a vertical plane without developing any indications of a capsular nature. The conclusion that these carpels were many seeded also rests upon the manner in which compression has occurred and the resulting irregularities of surface, which differ from what would be shown if one or a few large seeds had been present.

The genus *Monocarpellites*, to which the present species is referred, is a form genus established by Perkins in 1904 and based upon abundant material from the Eocene lignite deposits at Brandon, Vt. Specimens of *Monocarpellites* are among the most abundant fossils at Brandon, and Perkins has described 11 different species based upon differential features that are more or less well marked but quite obviously not of specific grade. Although the Wilcox *Monocarpellites* resembles several of these so-called species from the Brandon lignite it can not be conclusively identified with any one of them, so that in the present unsatisfactory state of our knowledge of fossil fruits it must necessarily be considered to represent a new species.

In this connection attention should be called to the genus *Hightea*, which was described by

Bowerbank[24] from the abundant pyritized fruits found in the London clay of Sheppey (Ypresian). As elucidated by Bowerbank the genus *Hightea* possessed a one-celled valveless pericarp with large 4 to 6 angled placena and numerous down-bearing seeds, these fruits having every appearance of being five or more numerously valved capsules. *Hightea* is very abundant at Sheppey, and Bowerbank described no less than 10 so-called species, which are subject to the same limitations as Perkins's numerous species of *Monocarpellites*.

Although it is impossible to advance conclusive opinions without having studied a large suite of specimens, it seems probable that *Hightea* and *Monocarpellites* are congeneric, thus affording an important item for the correlation of these three widely separated deposits, valuable chiefly for the evidence it affords of the age of the Brandon lignite, as the parallelism between the London clay and the Wilcox is already well established.

Occurrence: Spink's clay pit, near Paris, Henry County, Tenn.

Family STERCULIACEAE.

Genus STERCULIA Linné.

Sterculia wilcoxensis Berry, n. sp.

Plate XIV, figures 1, 2; Plate XV, figures 3, 4.

Sterculia puryearensis Berry, U. S. Geol. Survey Prof. Paper 91, pl. 72, fig. 3 (not other figures of this species), 1916.

Leaves (in discovered material) trilobate, divided from one-half to two-thirds of the distance to the base into a median conical to slightly ovate lobe and lateral, somewhat narrower conical lobes. All are acuminate, and all may be of equal length, or the median lobe may be somewhat longer. The intervening sinuses are open and rounded and of varying depth; their degree of openness depends on the attitude of the lateral lobes, for although the angle of divergence of the lateral primaries with the midrib is practically uniform, the lateral lobes and the primaries forming their midveins may be either incurved or recurved, as shown in the accompanying illustrations. The margins are entire and the texture coriaceous. Length ranging from 12 to 16 centimeters; maximum width, between the tips of the lateral lobes, ranging from 9.75 to 15.25 centimeters and largely dependent on the attitude of the lobes. The petiole was evidently long and stout; it is preserved for 2 centimeters in one specimen. The midrib is stout and prominent, approximately straight or variously curved. The lateral primaries are approximately as stout and prominent as the midrib. They diverge from the midrib a considerable distance above the base, at angles between 35° and 45°, and are variously curved. The secondaries are thin and not especially prominent; they are numerous, regularly spaced, and subparallel, diverge at wide angles, and are abruptly camptodrome. The tertiaries are obscure.

The present species is, on the whole, well marked. It is in many ways similar to the European Oligocene species *Sterculia labrusca* Unger[25] and, like that and most other living and fossil species, may have varied to a fewer or greater number of lobes, although all the specimens known at present are trilobate. It may be properly considered ancestral to the Claiborne species *Sterculia labruscoides* Berry, a somewhat smaller form with more conical lobes and rounded base.

A fragment of this species from Puryear, Tenn., was figured in 1916 and referred to *Sterculia puryearensis* Berry. Recent collections from Louisiana show that this fragment represents the present species, which is quite distinct from the much larger and more ovate lobed and lobate *Sterculia puryearensis*. It adds a second and striking representative of this genus to the flora of the Wilcox group, in which it is also represented by the fruits referred to the genus *Sterculiocarpus*.

Occurrence: Puryear, Henry County, Tenn.; collected by E. W. Berry. Goss pit, half a mile east of Mansfield, De Soto Parish, La.; collected by O. M. Ball. Carrizo sandstone half a mile west of Carrizo Springs, Dimmit County, Tex.

Genus STERCULIOCARPUS Berry.

Sterculiocarpus eocenicus Berry.

Plate XV, figure 5; Plate XVI, figure 1.

Sterculiocarpus eocenicus Berry, U. S. Geol. Survey Prof. Paper 91, p. 288, pl. 74, figs. 1-3, 1916.

The present specimen adds considerably to our knowledge of this form. It is relatively slightly longer and narrower than the type and shows that the capsules were tardily loculicidally dehiscent and contained many small elongated seeds on parietal placentae. It thus differs from the other known species, namely *S. sezannelloides* Berry, in which the placentae were axile and the dehiscence septicidal.

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[24] Bowerbank, J. S., A history of the fossil fruits and seeds of the London clay, p. 25, pls. 7-9, 1840.

[25] Unger, Franz, Die fossile Flora von Sotzka, p. 45, pl. 28, figs. 1-11, 1850.

Occurrence: Goss pit, half a mile east of Mansfield, De Soto Parish, La.; collected by O. M. Ball.

Genus HELICTOXYLON Felix.

Helictoxylon wilcoxianum Berry, n. sp.

Plates XVII and XVIII.

Transverse section: Vessels large, oval, very numerous and closely spaced, generally single, sometimes in oblique pairs. Rays undulating, broad, several cells wide, charged with gum. Parenchyma filling most of the space between the rays and vessels. Prosenchyma well distributed as single or double strands in the parenchyma, with greatly thickened walls.

Radial section: Vessels reticulately marked or obscurely pored. Parenchyma much septate, without discernible pitting. Prosenchyma with pointed ends, sparingly septate, with ray of very minute pores on the radial walls. Rays high, the marginal cells square, the central long and narrow. Pitting obscured by gum.

Tangential section: Vessels often with oblique scalariform perforations; walls reticulately marked. Rays fusiform elliptical, 8 or 9 cells wide medianly, 25 to 35 cells high, the normal ray frequently continued in one or both directions by uniserial large rectangular cells. Parenchyma of short rectangular cells without discernible pitting. Prosenchyma sparingly septate, with a row of minute pores.

The wide rays, the abundance of xylem parenchyma, and the prosenchyma with simple pits indicate that this wood represents some species of Sterculiaceae, and the size and abundance of the vessels suggest a liana. As it is not possible to make comparisons with recent material, nor desirable to propose a new generic term such as *Sterculioxylon*, the species is referred to the genus *Helictoxylon*, proposed by Felix[26] for two species from the Oligocene of Antigua. Species are also known from the Tertiary of Java, Luzon, Galicia, and Hungary. The Wilcox species appear to be entirely distinct from previously described forms.

Occurrence: Two miles east of Naborton, De Soto Parish, La.

Order THYMELEALES.

Family LAURACEAE.

Laurus verus Berry, n. sp.

Plate XVI, figures 2–7.

I am fortunate in having several specimens of this fruit preserved as a ferric oxide replacement in Wilcox sands. Several are detached from the persistent calyx with the hilum obscured, and their identity would be questionable were it not for the finding of specimens with the calyx attached which came loose from the calyx, showing the umbo. In form the fruit is a considerably prolate spheroid varying considerably in size, the minimum and maximum sizes observed being 11 millimeters in length by 7 millimeters in maximum diameter and 15 millimeters in length by 9.5 millimeters in maximum diameter. The distal end comes to a not very obvious point. The surface is smooth and polished. The calyx is small, thick, coriaceous, and gamosepalous, the sepals represented by six conical or rounded upright marginal teeth, 3.5 to 4.5 millimeters in diameter and 2.5 to 3 millimeters high. Peduncle stout and curved, 2.5 to 4 millimeters in length. These are well shown in the accompanying figures. The question of their proper generic reference may be left in abeyance for the present, as a considerable number of the genera of the Lauraceae have comparable fruits. The term *Laurus* is used in the present connection purely as a form genus implying their reference to this family. The only lauraceous leaves found in association with these fruits are those of *Oreodaphne salinensis* Berry, and even these are rare. It may be assumed that these fruits floated a considerable distance from their point of origin, as is frequently the case with modern lauraceous fruits. I am inclined to consider these fossils as representing the genus *Cinnamomum*, but this is entirely a matter of personal opinion.

A considerable number of fossil fruits belonging to this family have been described. Among them those from the Oligocene of Trotha and Bornstadt, in Saxony, described by Friedrich,[27] are exceedingly like the Louisiana fruits. Without any pretense at citing records, attention may also be called to the *Cinnamomum* fruits recorded by Friedrich[28] from the Oligocene and those recorded by Heer[29] from the Miocene of Europe.

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[26] Felix, J., Fossile Hölzer Westindiens, p. 18, 1883.

[27] Friedrich, P., Beiträge zur Kenntniss der Tertiärflora der Provinz Sachsen, pp. 128, 234, pl. 15, fig. 9; pl. 31, fig. 10, 1883.

Occurrence: Goss pit, half a mile east of Mansfield, De Soto Parish, La.; collected by O. M. Ball.

Genus LAURINOXYLON Felix.

Laurinoxylon branneri Knowlton.

Laurinoxylon branneri Knowlton, Arkansas Geol. Survey Ann. Rept. for 1889, vol. 2, p. 256, pl. 9, figs. 8, 9; pl. 10, figs. 1, 2; pl. 11, fig. 4, 1891.

Penhallow, Roy. Soc. Canada Trans., 3d ser., vol. 1, p. 98, figs. 6–8, 1908.

Berry, U. S. Geol. Survey Prof. Paper 91, p. 314, pl. 16, figs. 6–10, 1916.

This species was described in previous reports and doubtfully recorded from the Wilcox. It occurs in the Claiborne of Arkansas and Texas, according to the identifications of Knowlton and Penhallow.

A specimen from the Wilcox at Shreveport, La. (No. 207), appears to be identical with the type. It is rather indifferently preserved and adds nothing to our knowledge of the species.

Laurinoxylon wilcoxianum Berry, n. sp.

Plate XIII.

Transverse section: Vessels single or in radial pairs or triplets, rarely more, occasionally in tangential pairs or excentric. Well distributed but sparse, no zonal arrangement or diminution in size throughout the year, oval in cross section, thin walled. Prosenchyma abundant, the walls scarcely thickened. Xylem parenchyma abundant, showing a tendency to an arrangement in tangential bands. Rays undulating, one to three cells wide, full of gum.

Radial section: Vessels full of tyloses, with pitted walls. Rays varying in height from 2 to 18 cells; marginal cells square, about twice the height and one-half the length of the central cells, their horizontal and end walls with numerous simple pits. Rays mostly full of gum. A constant feature is the large vertical series of ray cells running from one ray to another. Prosenchyma thin, fusiform; no markings or septation seen, although in specimens from the Claiborne group that appear to belong to this species the prosenchyma is irregularly septate. Parenchyma about twice as wide as the prosenchyma, abundantly septate; no pits seen in the Wilcox material but with numerous round pores in the Claiborne material.

Tangential section: Rays closely crowded, 2 to 3 cells wide, connected by uniserial stringers of large rectangular cells, all full of gum.

This species appears to be distinct from previously described forms. It is abundant in the Wilcox but is usually rather poorly preserved, having suffered much from decay before silicification. Much better preserved material of this species is present in the Yegua formation of Texas and will be fully described and figured in my account of the Claiborne and Jackson floras. Sections have been cut from trunks from the following localities: Half a mile southwest (214) and 1 mile west (212) of Naborton, De Soto Parish, La.; near Dabney (242), Montgomery County, Miss.; Piney Creek (238), 10 miles east of Bolivar, Hardeman County, Tenn. All from beds of upper Wilcox age except the last, which is probably middle Wilcox.

Order MYRTALES.

Family COMBRETACEAE.

Genus TERMINALIA Linné.

Terminalia lesleyana (Lesquereux) Berry.

Plate XVI, figure 8.

Terminalia radobojensis Heer. Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1871, Suppl., p. 15, 1872.

Magnolia lesleyana Lesquereux, Am. Philos. Soc. Trans., vol. 13, p. 421, pl. 21, figs. 1, 2, 1869; Tertiary flora, p. 248, pl. 44, figs. 1–3, 1878; U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1871, Suppl., p. 14, 1872.

Knowlton, U. S. Geol. Survey Prof. Paper 101, p. 313, pl. 82, figs. 1, 2, 1917.

Terminalia lesleyana Berry, U. S. Geol. Survey Prof. Paper 91, p. 323, pl. 89, 1916.

A large specimen of this species from Louisiana is figured in the present paper. Since my account of the Wilcox flora was published Knowlton[30] has given a very excellent account of the Raton flora. In that paper the present species is transferred back to *Magnolia*, although no reasons are given. I have compared the fossil with a large amount of recent material of both *Magnolia* and *Terminalia* and am satisfied that the fossil is much more like the latter than the former, which was Lesquereux's original identification before it became the fashion to refer all large leaves to *Magnolia*.

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[28] Idem, p. 215, pl. 16, figs. 15, 16.

[29] Heer, Oswald, Flora tertiaria Helvetiae, vol. 2, pl. 91, fig. 8, 1856.

[30] U. S. Geol. Survey Prof. Paper 101, 1918.

Occurrence: Goss pit, half a mile east of Mansfield, De Soto Parish, La.; collected by O. M. Ball.

Order GENTIANALES.

Family APOCYNACEAE.

Genus APOCYNOPHYLLUM Unger.

Apocynophyllum mississippiensis Berry.

Apocynophyllum mississippiensis Berry, U. S. Geol. Survey Prof. Paper 91, p. 342, pl. 108, fig. 6, 1916.

The present material contains numerous leaves of this species which average about 20 per cent larger than those previously collected, indicating a leaf about 18 centimeters in length by 4 centimeters in maximum width.

Occurrence: Goss pit, half a mile east of Mansfield, De Soto Parish, La.; collected by O. M. Ball.

Apocynophyllum constrictum Berry.

Apocynophyllum constrictum Berry, U. S. Geol. Survey Prof. Paper 91, p. 344, pl. 103, fig. 4, 1916.

This species was based on the single specimen figured, which was collected from the Wilcox of Benton, Ark. Additional material was collected recently from the clay ironstone near Somerville, Tenn. This is of importance in showing that the constricted form that suggested the name of this species was not anomalous but the normal form of this lower Eocene *Apocynophyllum*. It is also important in confirming the conclusion that all the known fossiliferous Wilcox in Arkansas, Louisiana, and Texas is of upper Wilcox age, and that the Wilcox sediments were progressively transgressive in the region west of the present Mississippi River.

Occurrence: Half a mile south of Somerville-Whiteville road, Fayette County, Tenn.; collected by Russell F. Ryan.

POSITION UNCERTAIN.

Genus PTEROBALANUS Berry, n. gen.

The genus has the characters of the type and only known species. The name is derived from the Greek for winged fruit.

Pterobalanus texanus Berry, n. sp.

Plate XV, figures 1, 2.

Fruit of uncertain nature, either a many-seeded indehiscent capsule or a drupe with a readily flattened stone; the impression as preserved shows no trace of a stone and rather points to its having been a many-seeded capsule. The fact that the wings are so well developed rather precludes the inference that the central papillose portion of the specimen represents the base from which the essential part of the fruit had been broken away.

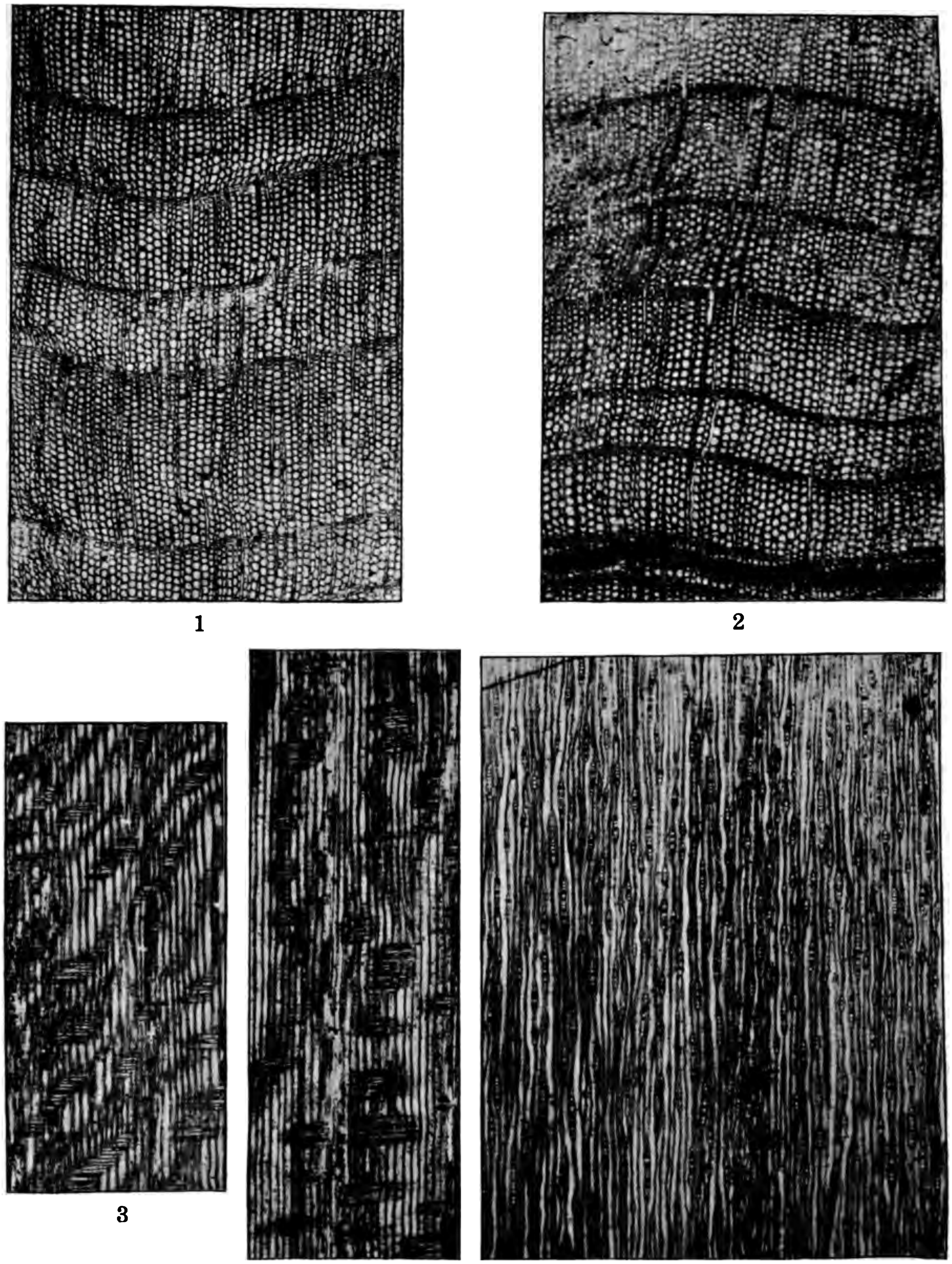
The remains consist of a stout stalk or peduncle, about 2.25 centimeters in length, slightly enlarged and curved proximad, expanding distad to form the margin of a central circular thickened papillose disk, which is 2 millimeters in diameter. From this margin diverge in a semicircular fashion about twelve wings or enlarged bracts. These are believed not to be segments of a calyx, because of their collective lack of symmetry, none being developed on the proximal or inner side of the central disk.

These bracts are separate lanceolate in outline, entire margined, acutely pointed, and about 5 millimeters in length by 1.5 millimeters in maximum width in their expanded median region. Each appears to have two longitudinal veins.

The systematic position of this interesting winged fruit is unknown, nor do I recall anything similar in the existing flora or in described fossil floras. It is based on the single specimen figured and its counterpart.

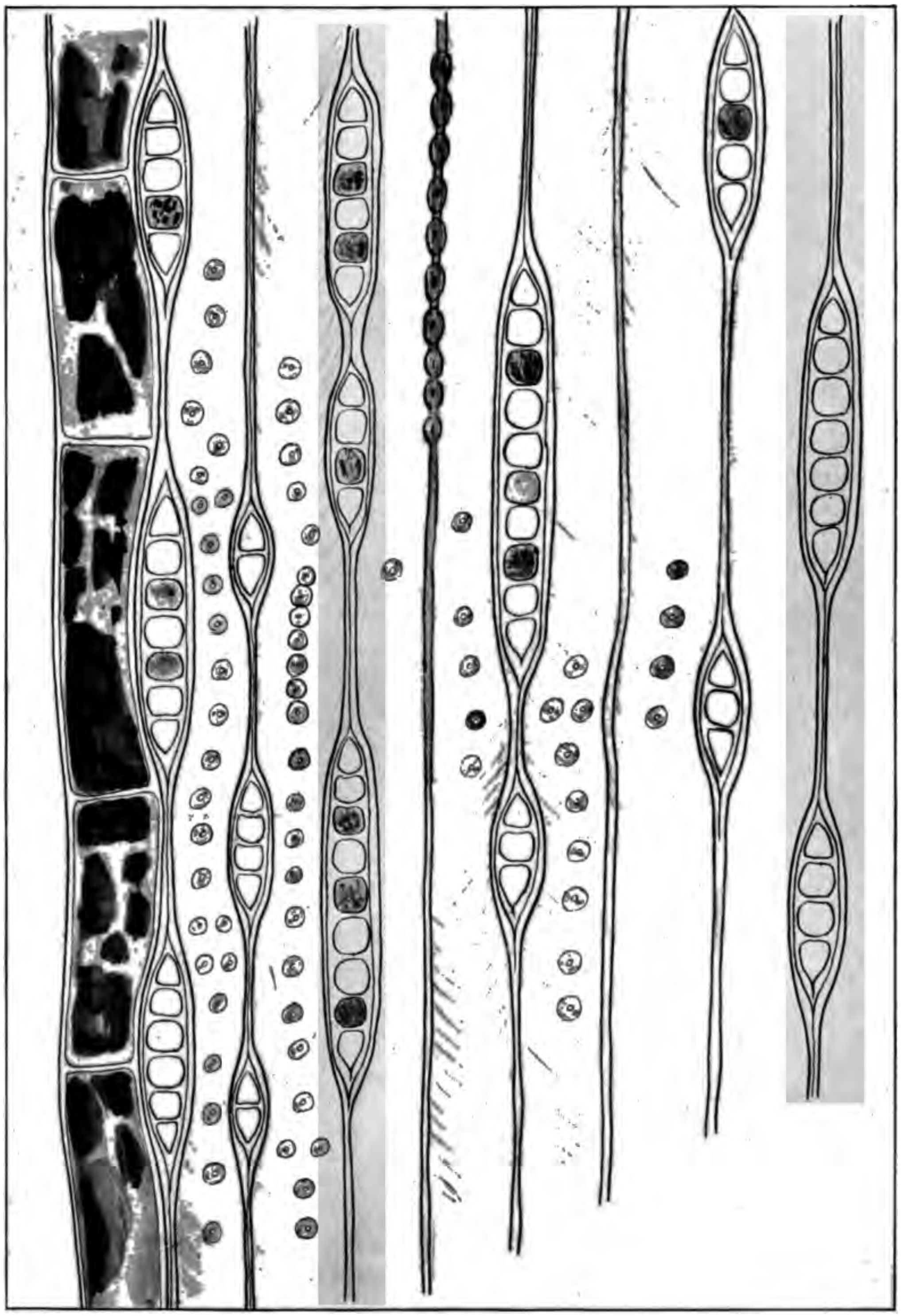
Occurrence: Carrizo sandstone at quarries half a mile west of Carrizo Springs, Dimmit County, Tex.

PLATES I-XVIII.



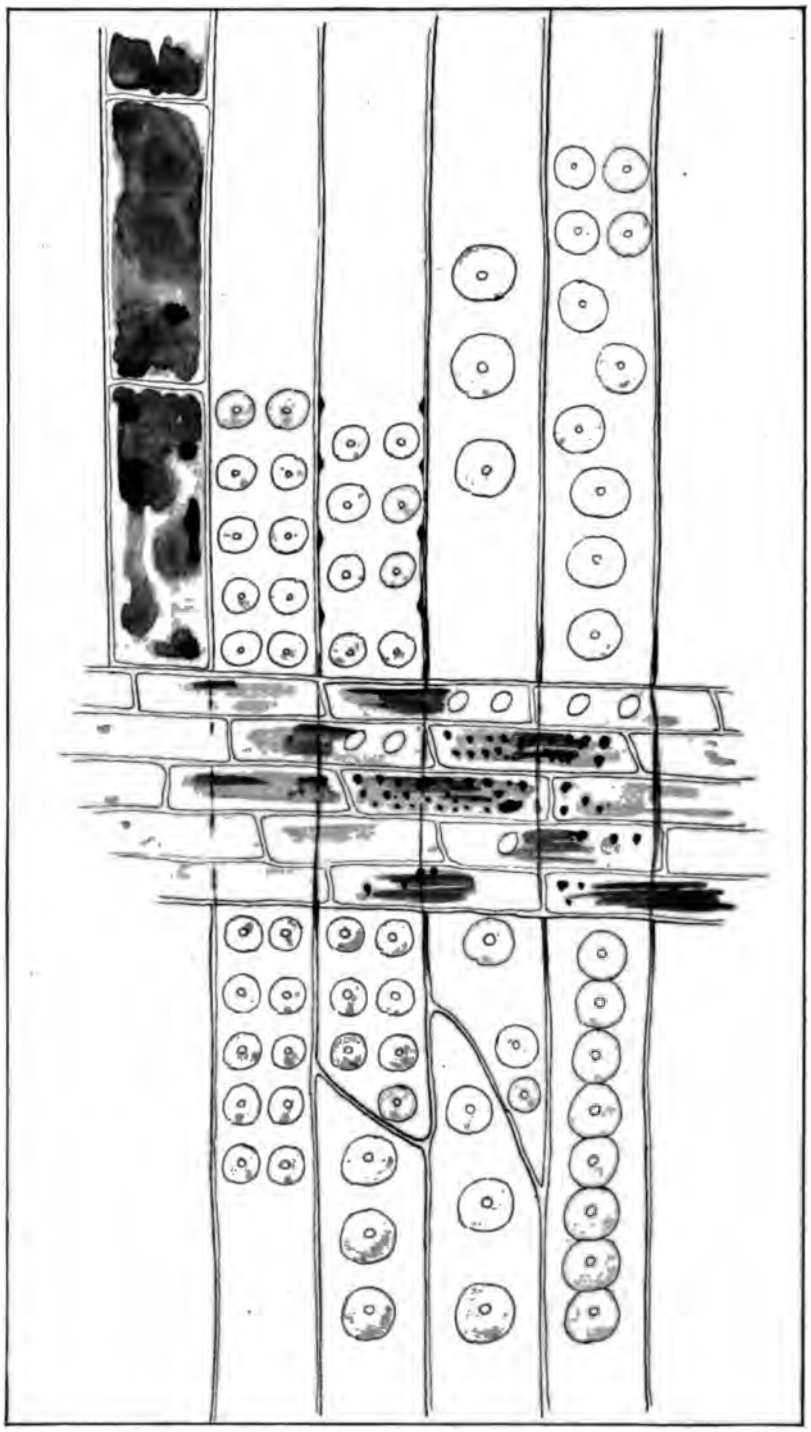
CUPRESSINOXYLON WILCOXENSE BERRY.

1, Transverse section showing growth rings from Shreveport, La.; 2, similar section from Caddo Lake, La.; 3, radial section from Caddo Lake, La.; 4, similar section from Shreveport, La.; 5, tangential section from Caddo Lake, La. All enlarged 20 diameters.



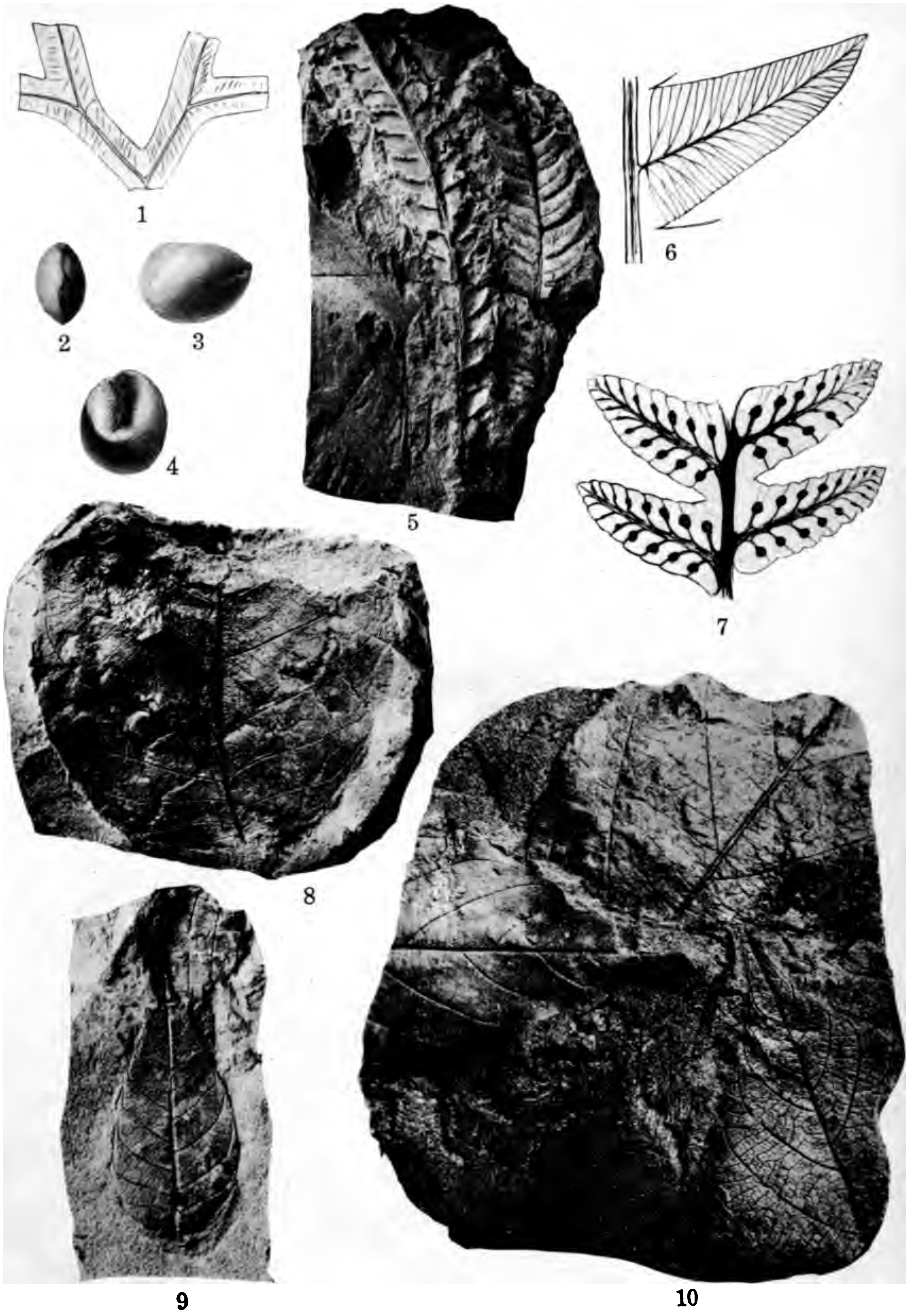
CUPRESSINOXYLON WILCOXENSE BERRY.

Tangential section from Shreveport, La., enlarged about 300 diameters.



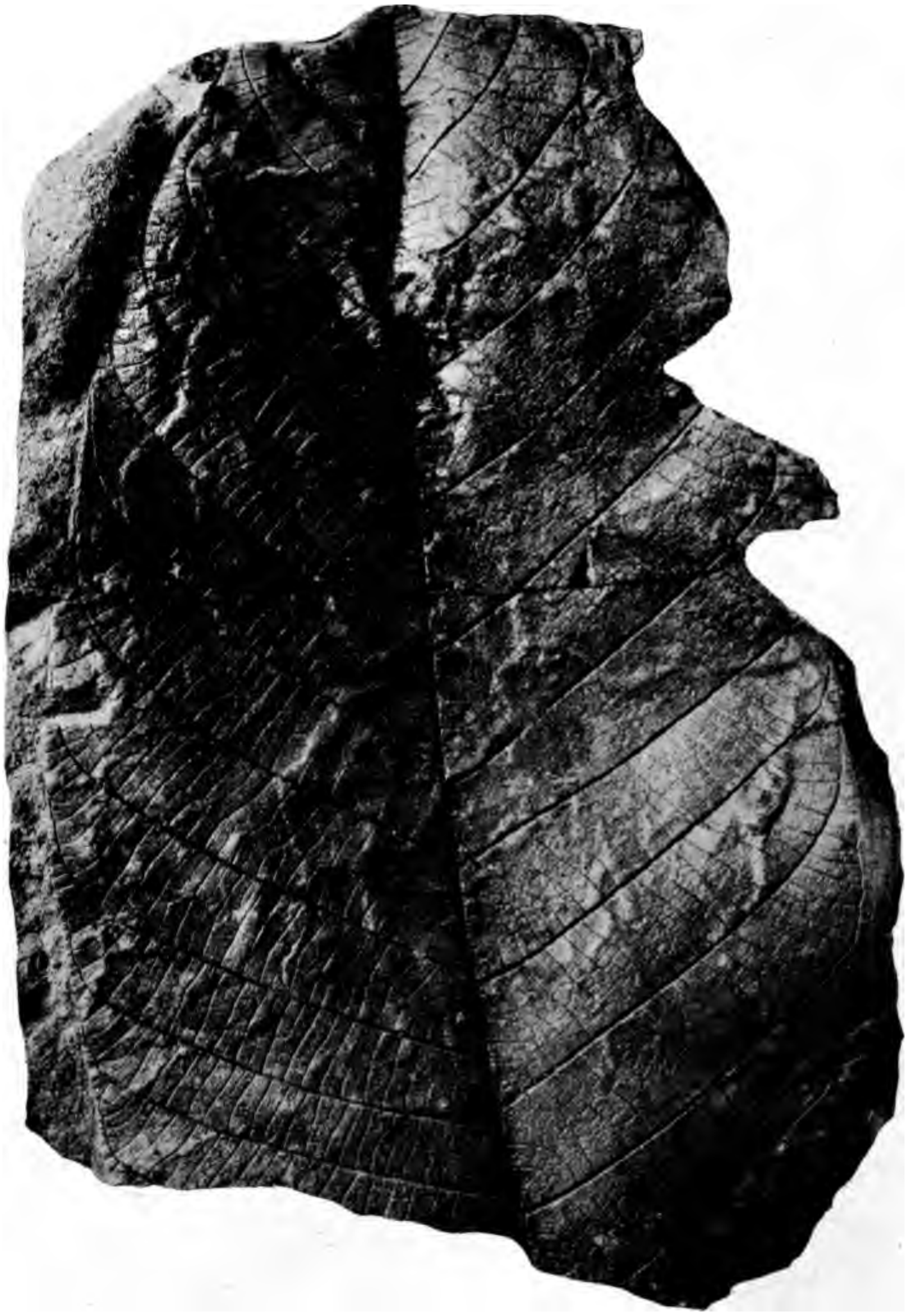
CUPRESSINOXYLON WILCOXENSE BERRY.

Radial section from Shreveport, La., enlarged about 300 diameters.



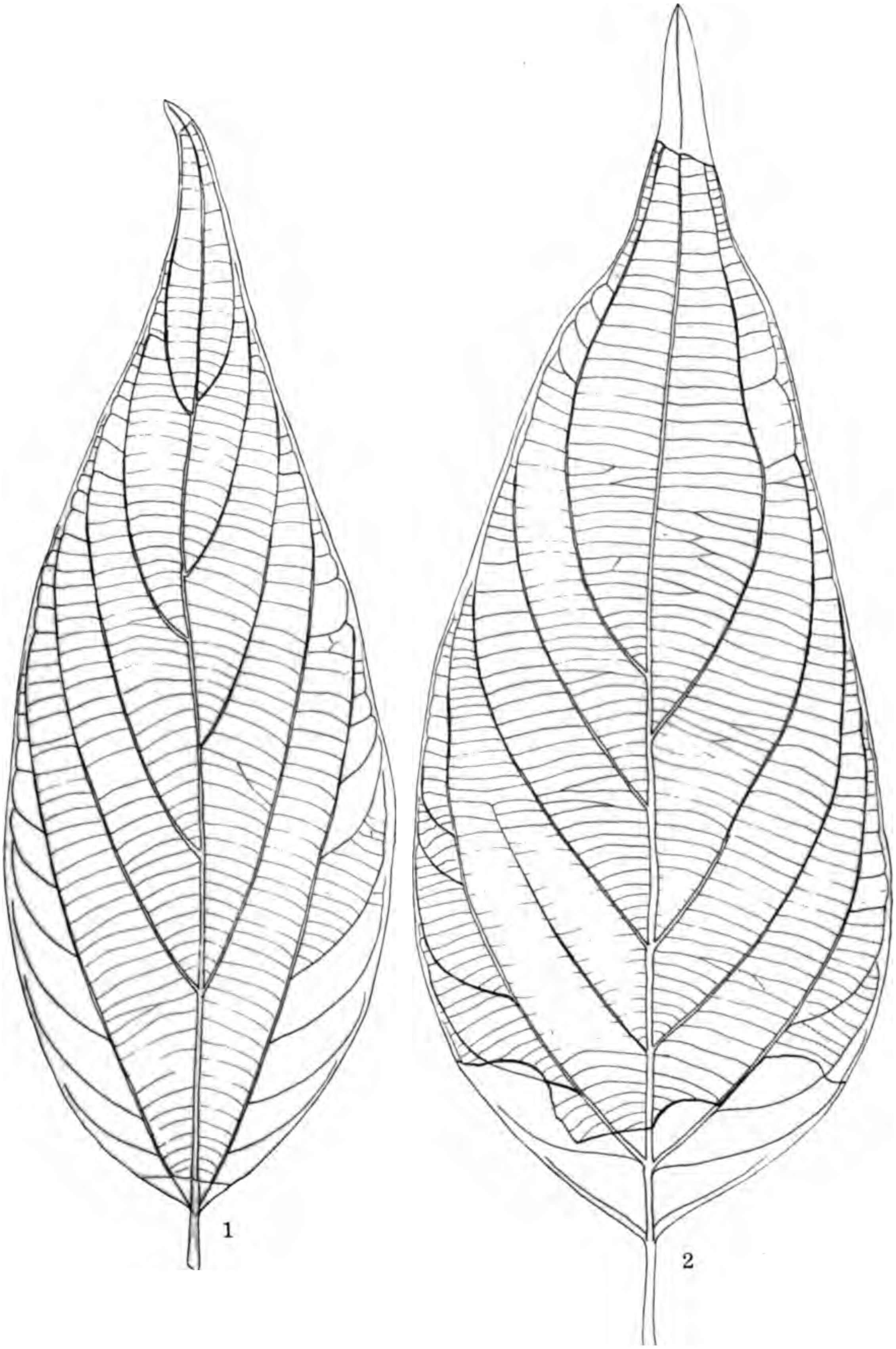
FOSSIL PLANTS OF THE WILCOX GROUP.

1. Marchantites stephensoni Berry, Jacksonville, Ark.; 2-4, Palmocarpon butlerensis Berry, near Oakville, Tex.; 5-7, Dryopteris cladophleboides Knowlton, Goss pit, near Mansfield, La. (6, pinnule to show venation, enlarged 5 diameters; 7, fertile pinnules, enlarged 5 diameters); 8-10, Artocarpoides balli Berry, Goss pit, near Mansfield, La.



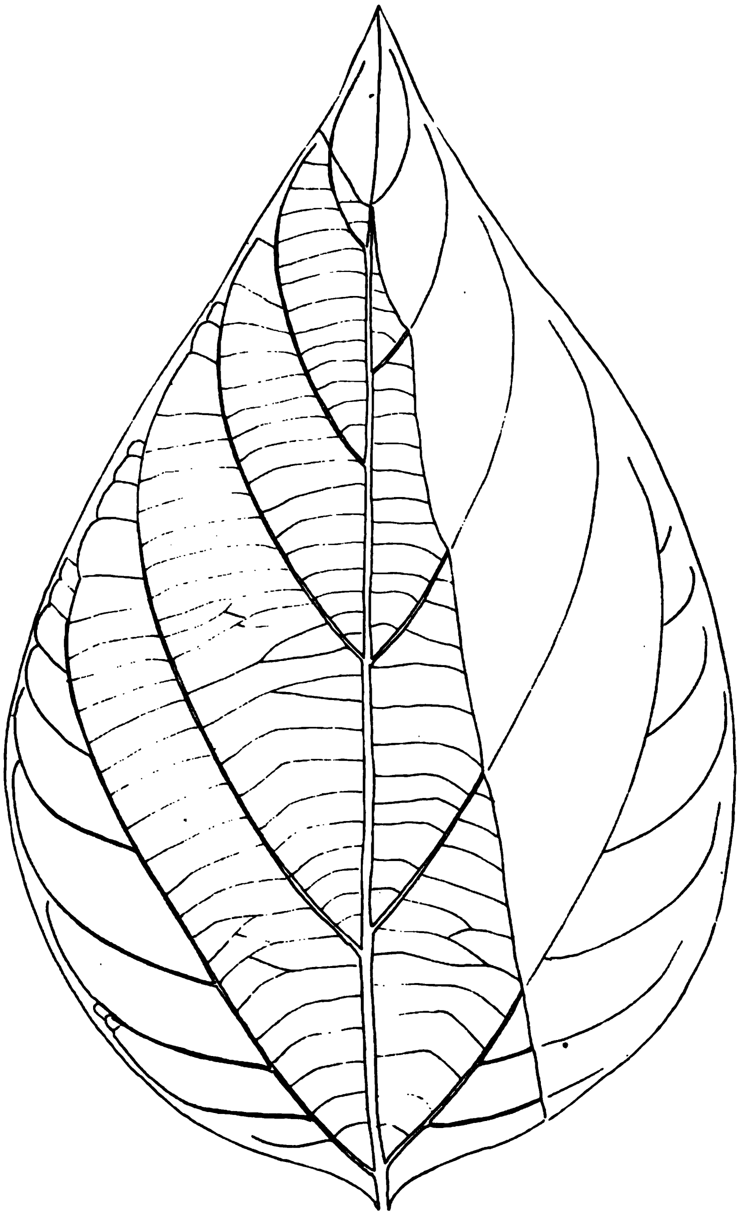
ARTOCARPOIDES BALLI BERRY.

A large leaf from Goss pit, near Mansfield, La.



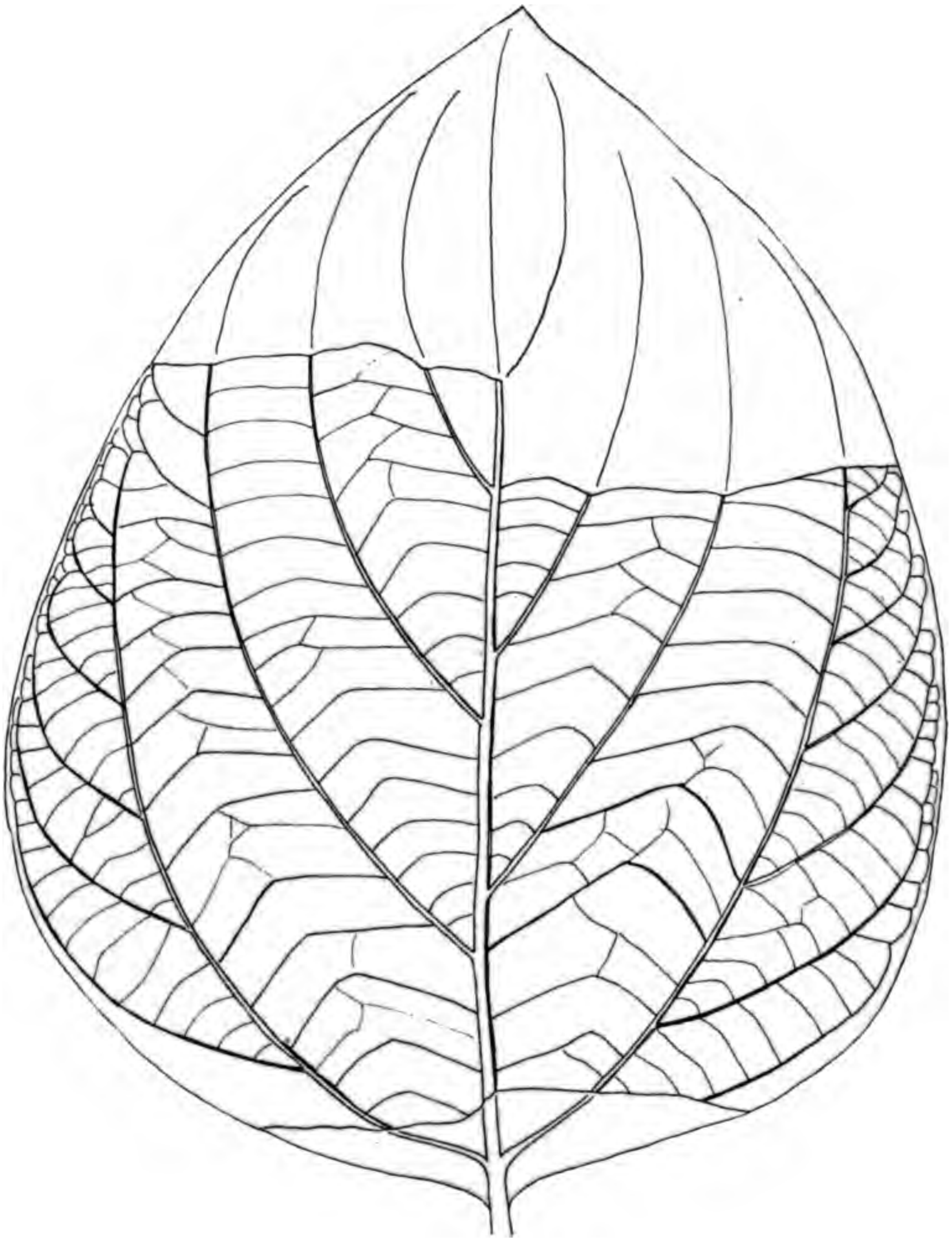
FICUS MISSISSIPPIENSIS (LESQUEREUX) BERRY.

Two of the large narrow forms from Goss pit, near Mansfield, La.



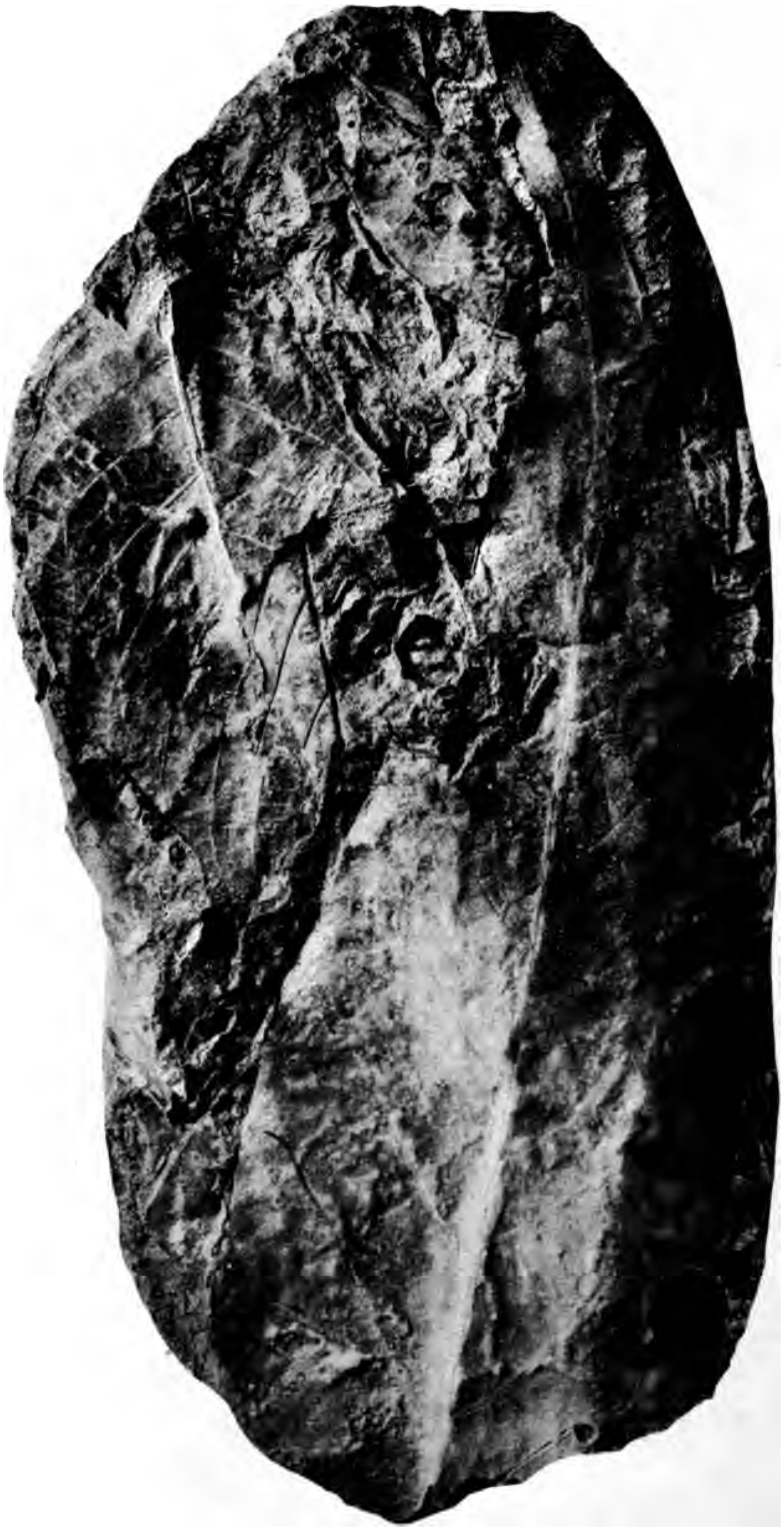
FICUS MISSISSIPPIENSIS (LESQUEREUX) BERRY.

Shorter and wider form from same locality as those figured on Plate VI.



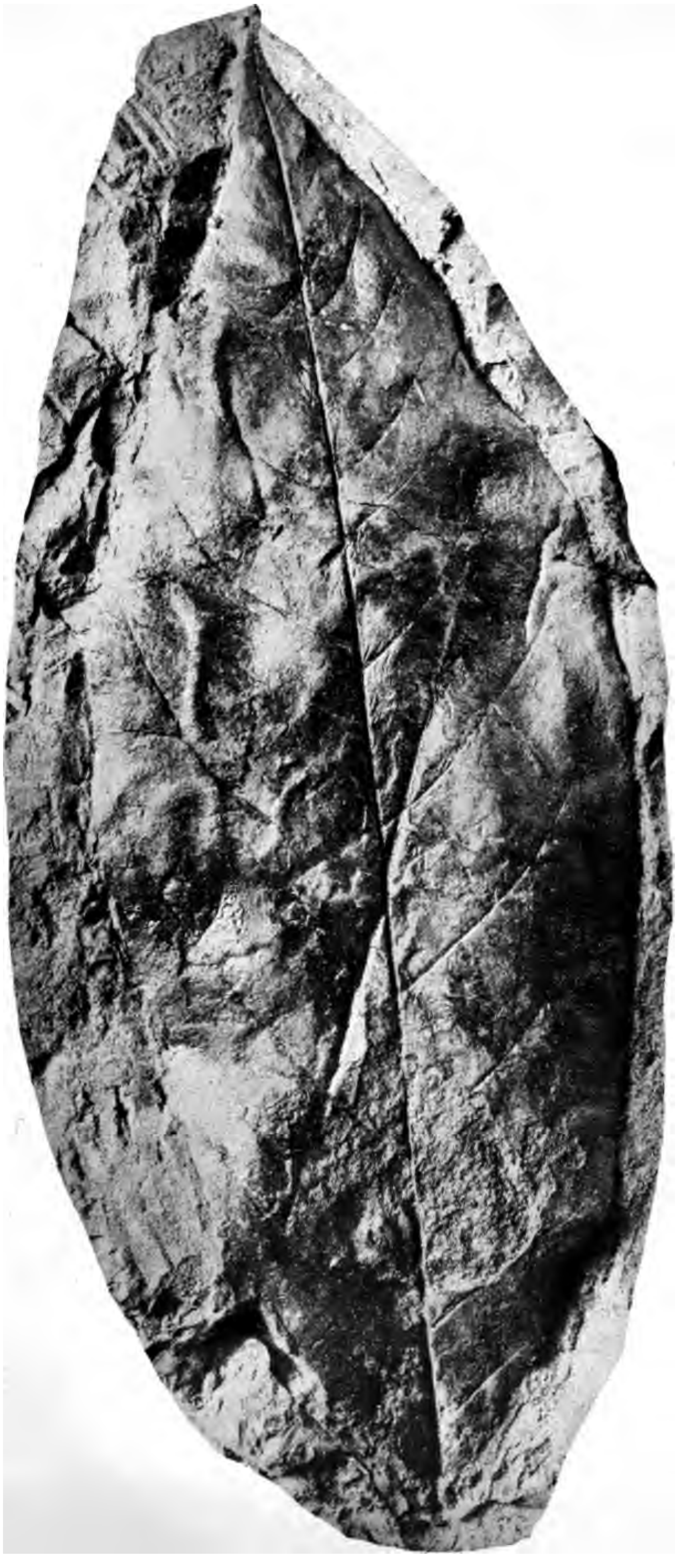
FICUS MISSISSIPPIENSIS (LESQUEREUX) BERRY.

Widest form from same locality as those figured on Plate VI.



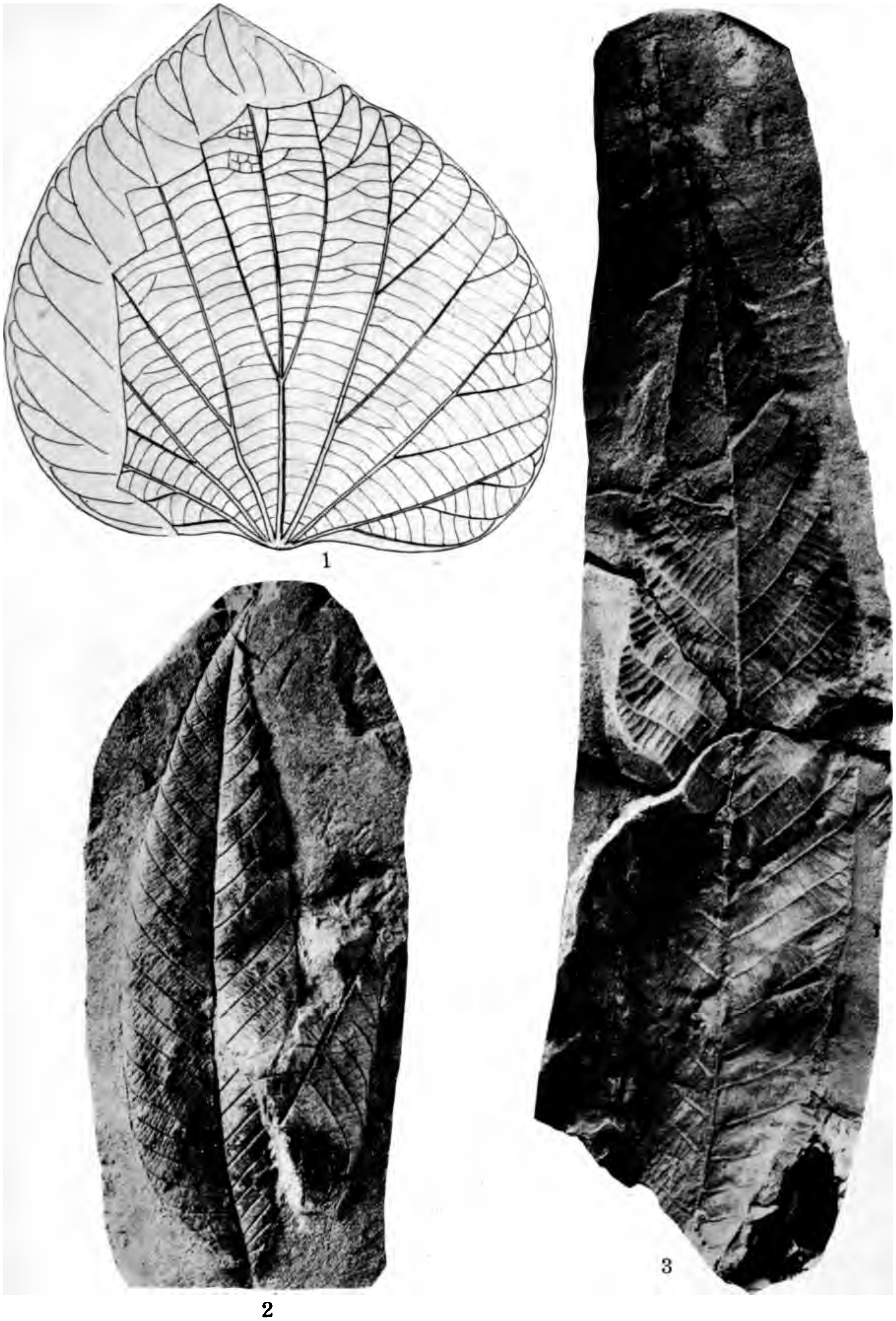
MAGNOLIA ANGUSTIFOLIA NEWBERRY.

From Goss pit, near Mansfield, La.



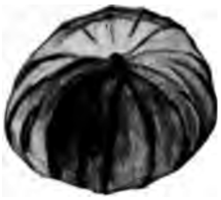
MAGNOLIA LEEI KNOWLTON.

From Goss pit, near Mansfield, La.



FOSSIL PLANTS OF THE WILCOX GROUP.

1, Menispermites cebathoides Berry; 2, 3, Rhamnus marginatus apiculatus Berry, small and large leaves. All from Goss pit, near Mansfield, La.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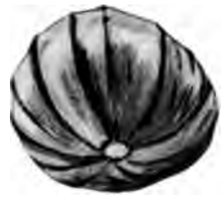
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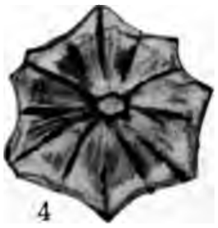
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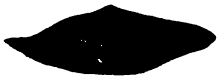
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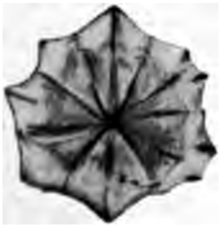
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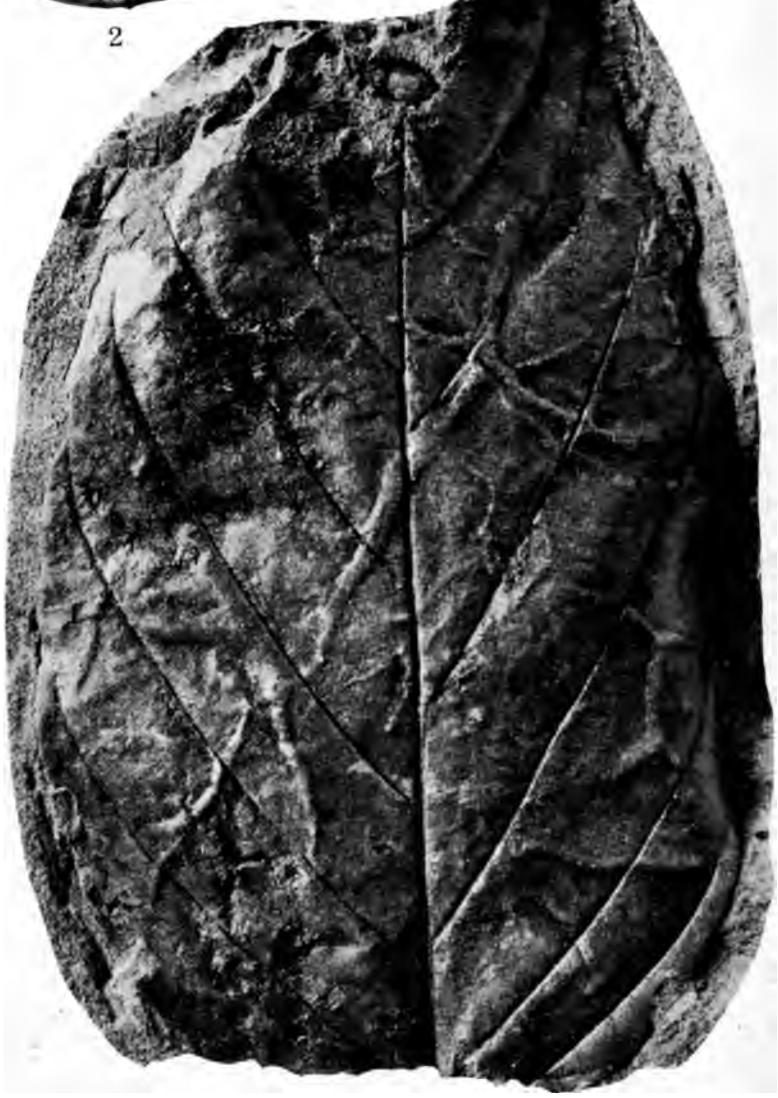
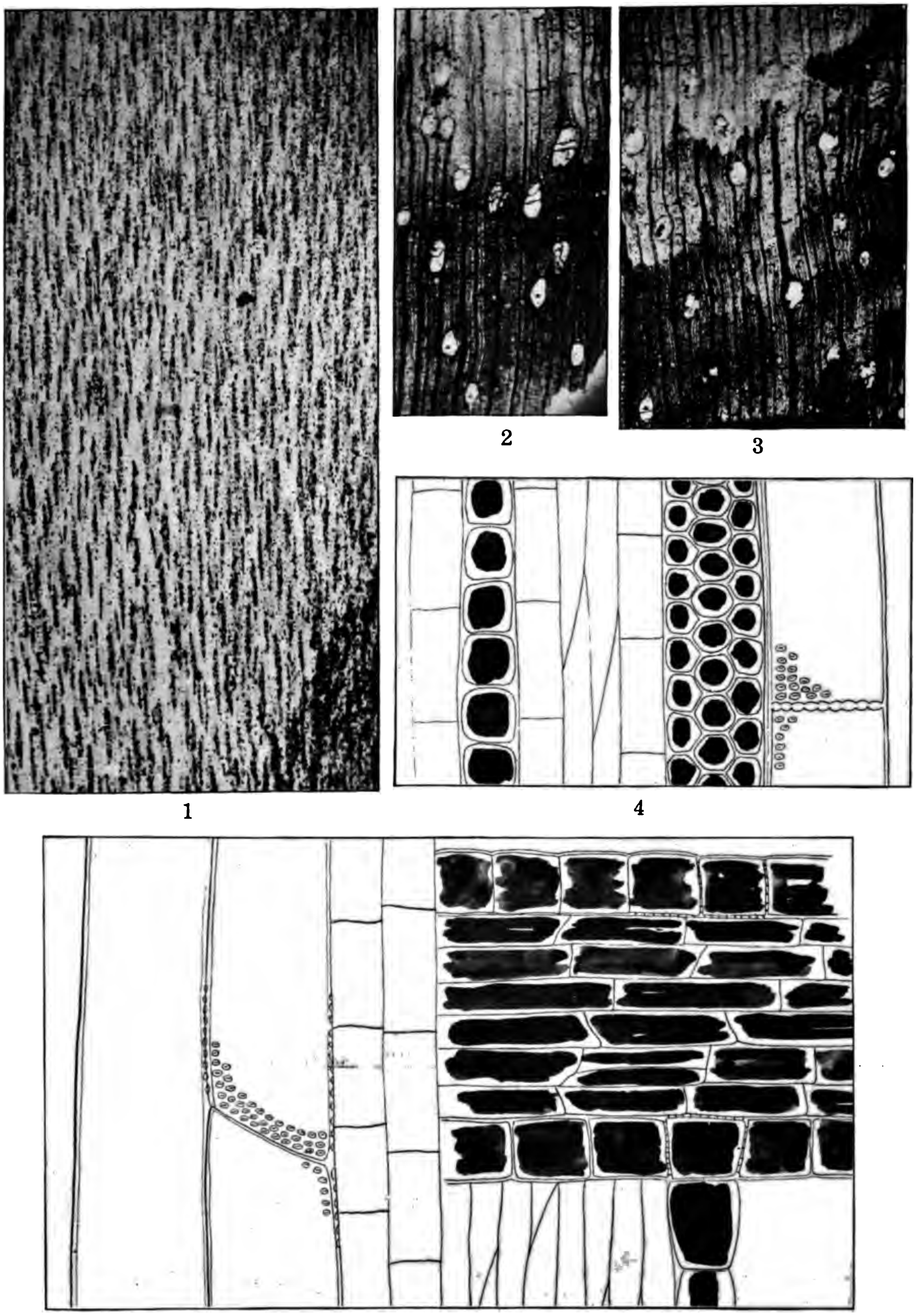

7

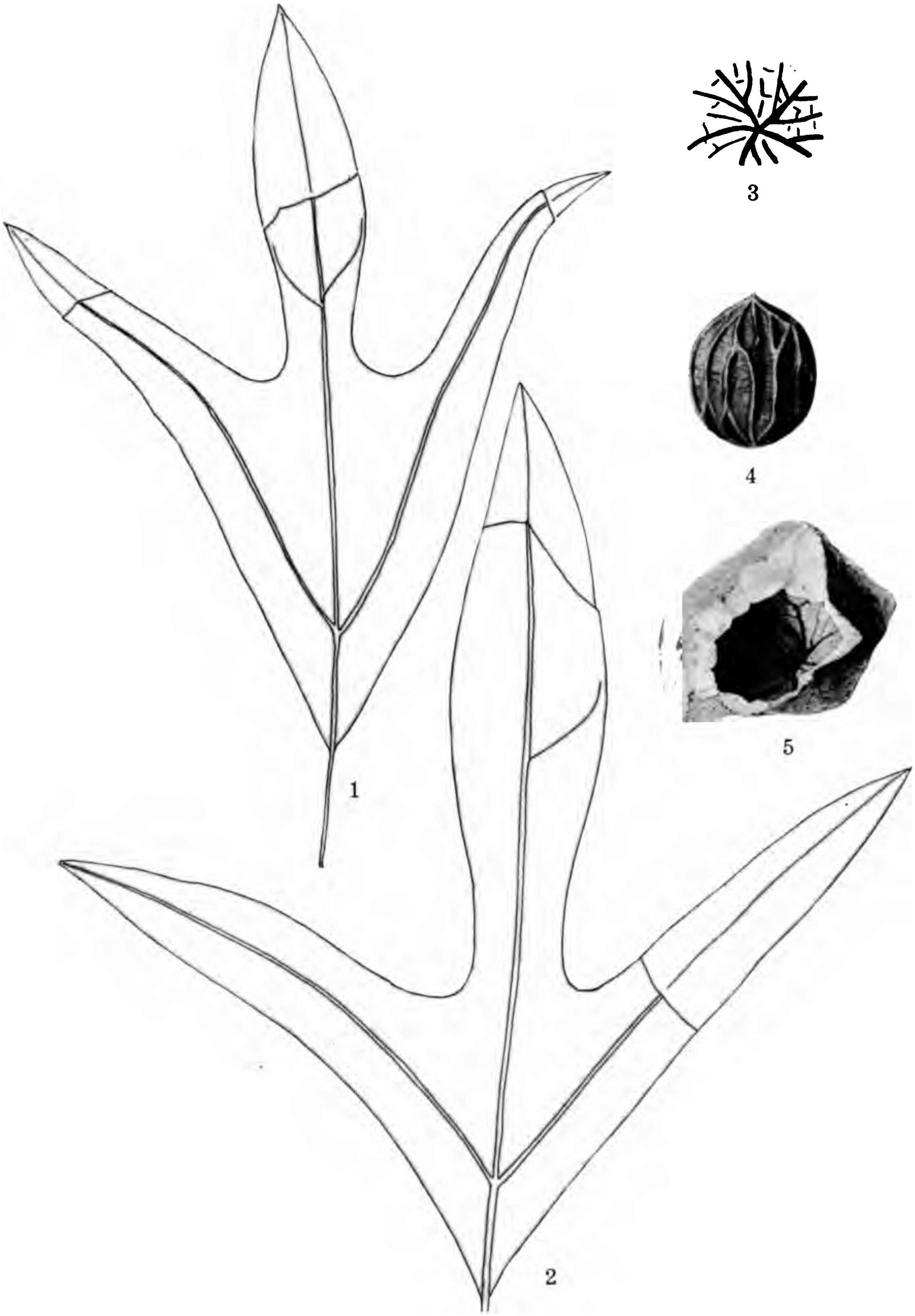
FOSSIL PLANTS OF THE WILCOX GROUP.

1-6, **Monocarpellites perkinsi** Berry, from vicinity of Paris, Tenn. (1-3, upper, lower, and side views of a partly compressed carpel; 4-6, lower, side, and upper views of a much compressed carpel); 7, **Rhamnites knowltoni** Berry, from Goss pit, near Mansfield, La.



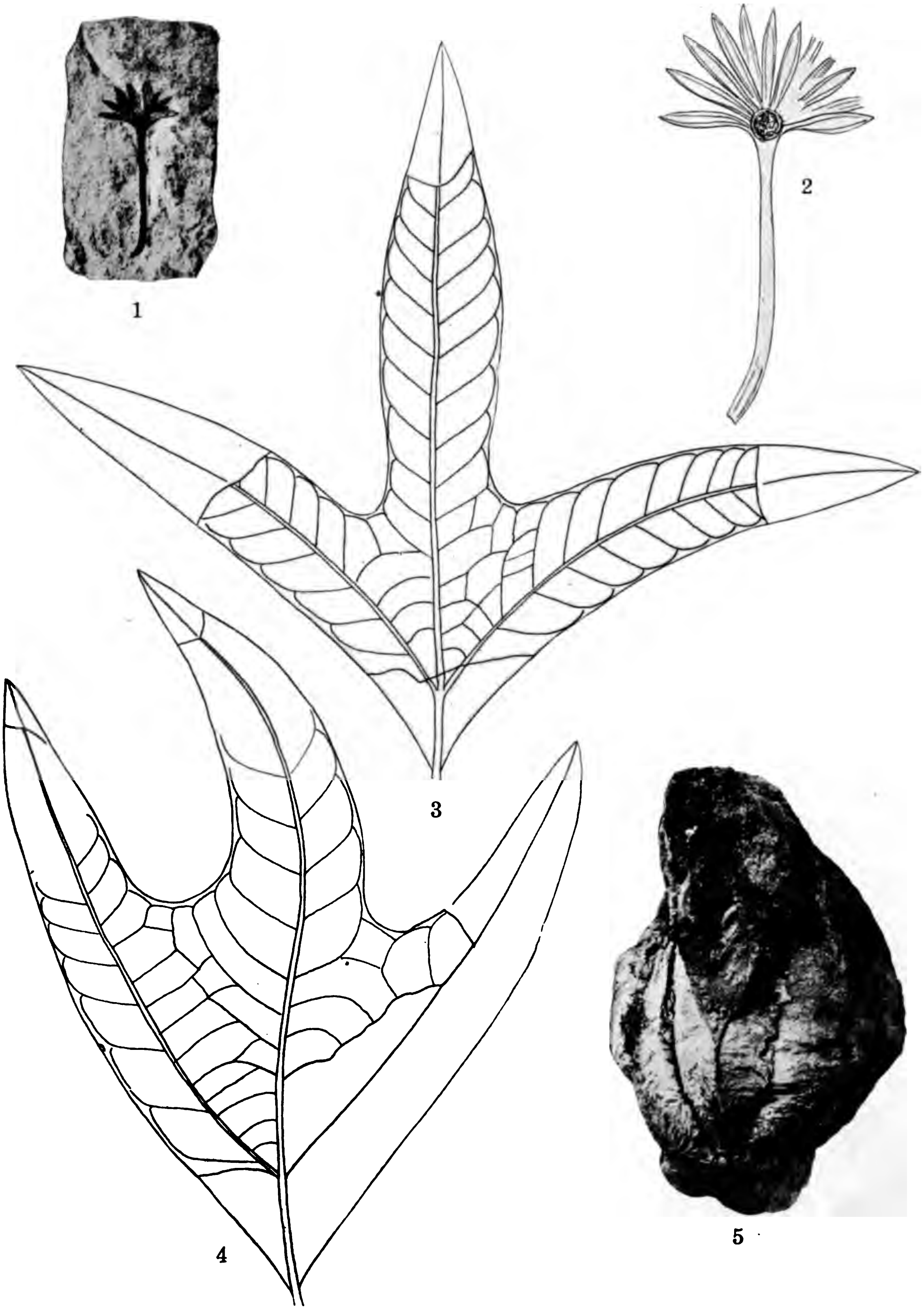
LAURINOXYLON WILCOXIANUM BERRY.

From vicinity of Dabney, Miss. 1, Tangential section enlarged 20 diameters; 2, 3, transverse sections, enlarged 20 diameters: 4, tangential section, enlarged 300 diameters; 5, radial section, enlarged 300 diameters.



FOSSIL PLANTS OF THE WILCOX GROUP.

1, 2, Sterculia wilcoxensis Berry, from Goss pit, near Mansfield, La.; 3-5, Calatoloides eocenicum Berry, from Butler salt dome, Tex.



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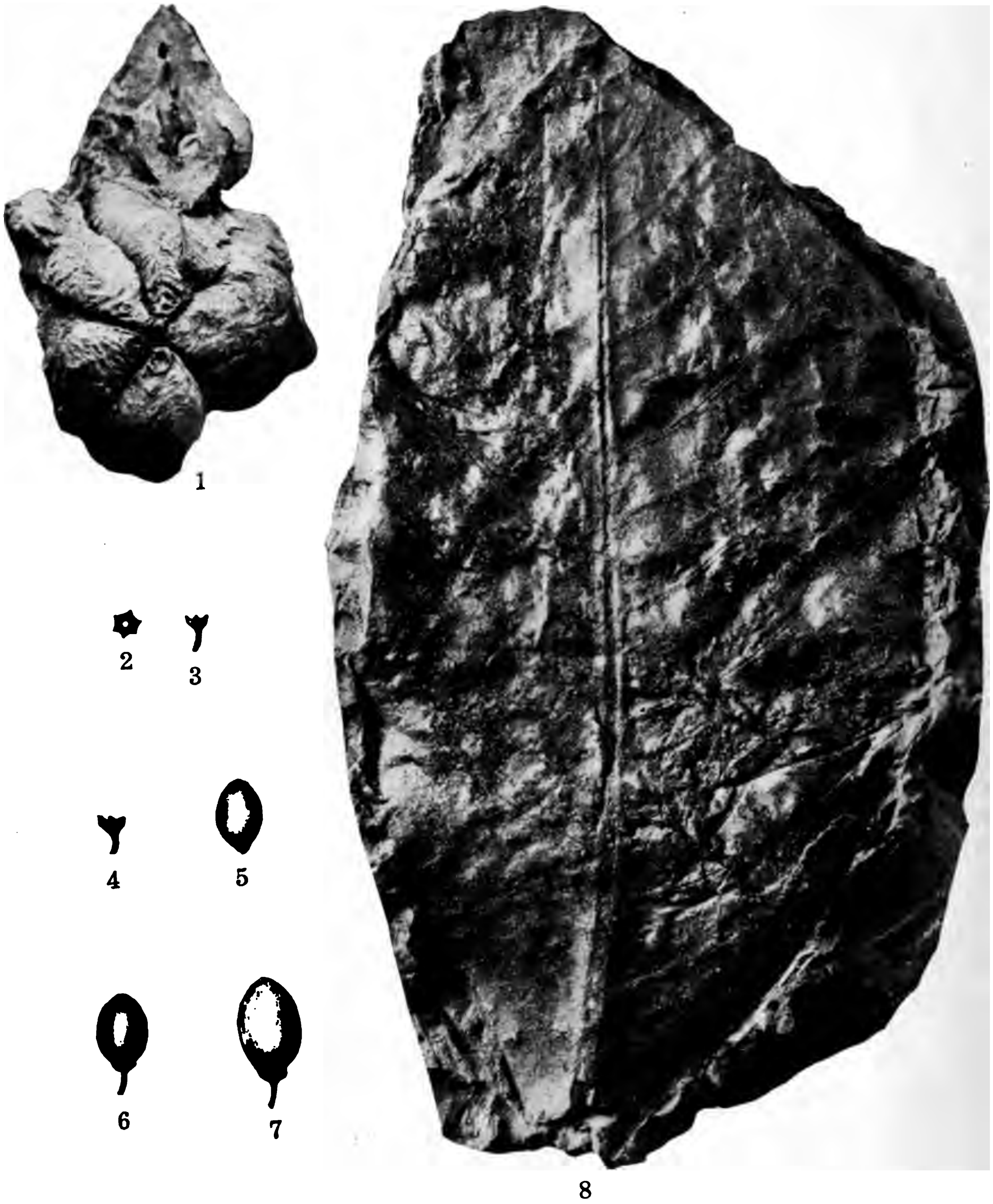
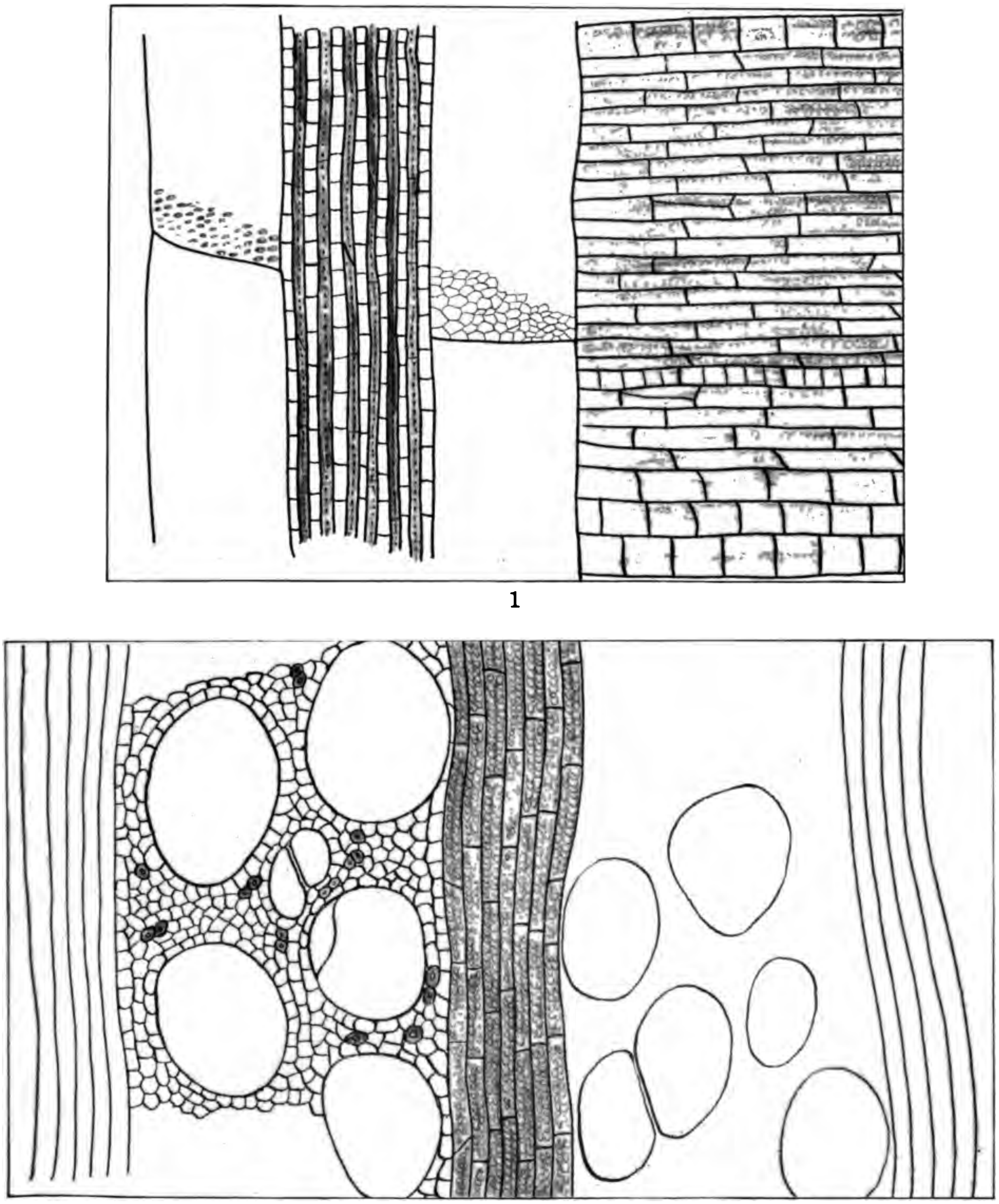
FOSSIL PLANTS OF THE WILCOX GROUP.

1-2, Pterobalanus texanus Berry; 3-4, Sterculia wilcoxensis Berry (3, Puryear, Tenn.; 4, Goss pit, near Mansfield, La.); 5, Sterculiocarpus eocenicus Berry (side view), from Goss pit, near Mansfield, La.



FOSSIL PLANTS OF THE WILCOX GROUP.

1, Sterculiocarpus eocenicus Berry (basal view); 2-7, Laurus verus Berry (2, persistent calyx from above; 3, calyx and peduncle from side; 4, another calyx and peduncle from side; 5, detached fruit; 6, 7, fruits with persistent calices and peduncles); 8, Terminalia lesleyana (Lesquereux) Berry. All from Goss pit, near Mansfield, La.



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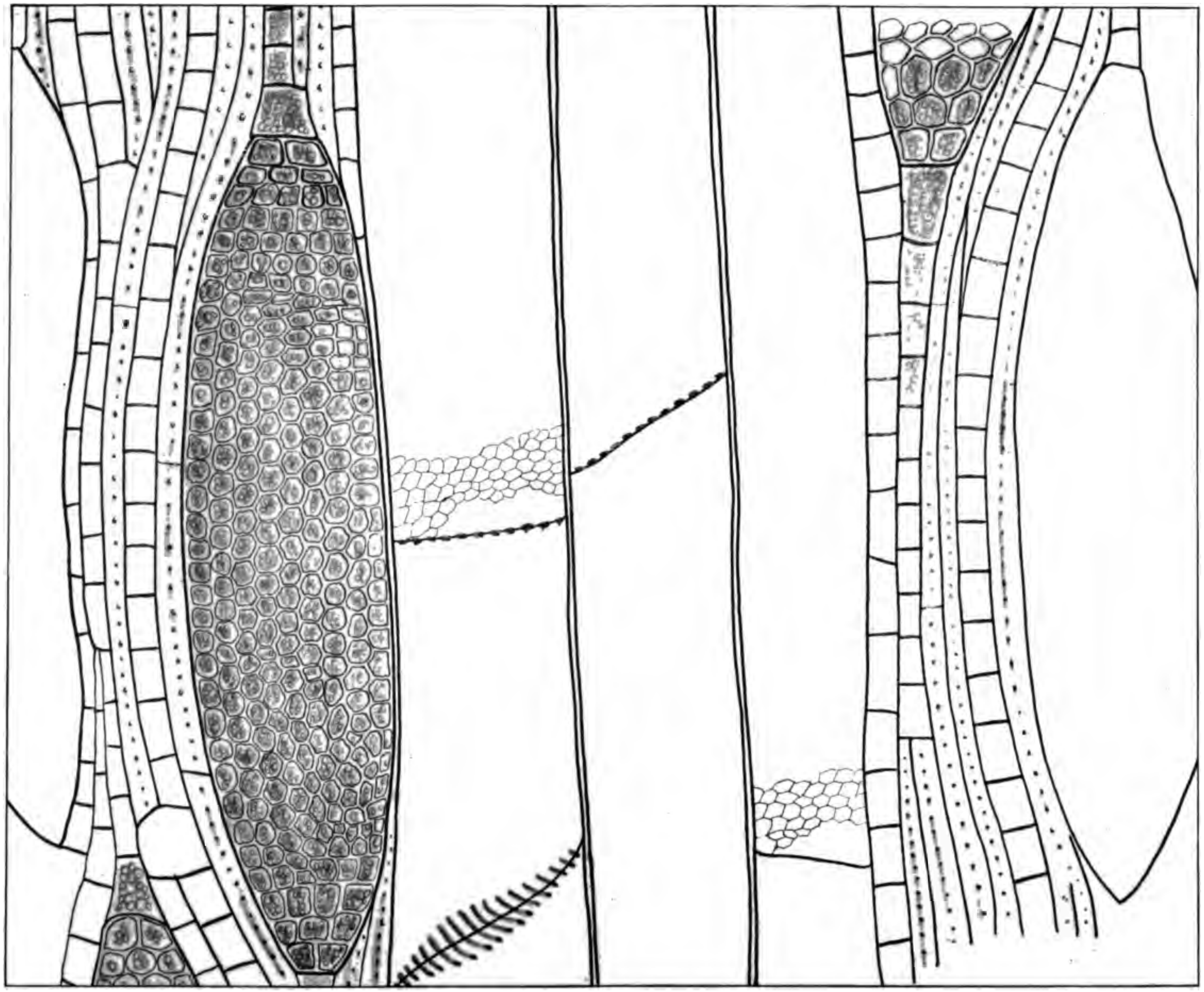
HELICTOXYLON WILCOXIANUM BERRY.

From vicinity of Naborton, La. 1, Radial section; 2, transverse section. Both enlarged about 300 diameters.



HELICTOXYLON WILCOXIANUM BERRY.

From vicinity of Naborton, La. Tangential section, enlarged about 300 diameters.

A SECTION OF THE PALEOZOIC FORMATIONS OF THE GRAND CANYON AT THE BASS TRAIL.

By L. F. Noble.

INTRODUCTION.

The thick series of horizontal strata of Paleozoic age which makes the greater part of the wall of the Grand Canyon is probably broadly familiar to more people than the strata exposed in any other area in the western United States. Each detail of form or color in the wall is so definitely associated with a bed or set of beds in the series that these strata are the very elements of the canyon landscape. Consequently they have been described not only by geologists but by many writers who have been interested in the Grand Canyon chiefly as a scenic spectacle.

In few areas, however, where the general character and succession of the rock formations is so familiar are the details of the stratigraphy so imperfectly known. In the Kaibab division of the Grand Canyon, which lies within the borders of the Grand Canyon National Park and is the best known and most visited part of the canyon, sections of the Paleozoic formations have been measured at four different places—(1) at Nunkoweap Valley, by Walcott;[1] (2) at Congress Canyon (now known as Red Canyon), along the Hance trail, by Frech;[2] (3) at Bright Angel (Cameron) trail, by Darton[3] and by me;[4] and (4) in the region about Shinumo Creek and Bass Canyon, by me.[5]

None of these sections shows in detail the lithology of all the Paleozoic formations at any one place, although some of them show the lithology of one or two formations in detail. Consequently none is adequate as a standard for close and accurate comparison and correlation of the formations from place to place in the canyon or for a detailed comparison with Paleozoic rocks exposed elsewhere in Arizona.

Realization of this lack of detailed stratigraphic information has led me to undertake a more thorough study of the Paleozoic rocks in the Grand Canyon than has been attempted previously. This work, begun in 1914 and continued in 1916 and 1920, has supplied material for a fuller description of the strata than was heretofore possible.

The present report includes a complete columnar section of the Paleozoic formations at the Bass trail, columnar sections of the Cambrian Tonto group at five other places in the Kaibab division, and a discussion of the age and correlation of the Paleozoic formations. Dr. Walcott has kindly furnished from his notes material for a fuller description of his section at Kanab Creek than has been published, and I have used this material freely in comparing and correlating the strata exposed at Bass Canyon, in the Kaibab division, with those exposed at Kanab Creek, in the Kanab division. I have also included in the report a section of the strata exposed in Cedar Mountain, a butte on the Coconino Plateau 2 miles east of the rim of the Grand Canyon near Tanner Canyon. This section carries the Grand Canyon geologic column up into the Mesozoic. The strata in Cedar Mountain, which is capped by the Shinarump conglomerate, of Triassic age, are the only remnants near the canyon rim of formations

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[1] Walcott, C. D., U. S. Geol. Survey Tenth Ann. Rept., pt. 1, p. 584, 1890.

[2] Frech, F., Section at Congress Canyon: Cong. géol. internat., 5^e sess., Compte rendu, pp. 476–481, 1894.

[3] Darton, N. H., A reconnaissance of parts of northwestern New Mexico and northern Arizona: U. S. Geol. Survey Bull. 435, p. 21, 1910; Guidebook of the western United States, Part C, The Santa Fe Route: U. S. Geol. Survey Bull. 613, pp. 124–130, 1915.

[4] Noble, L. F., The geologic history of the Bright Angel quadrangle, Ariz.: U. S. Geol. Survey Bright Angel topographic map.

[5] Noble, L. F., The Shinumo quadrangle, Grand Canyon district, Ariz.: U. S. Geol. Survey Bull. 549, pp. 60–73, 1914.

SECTION AT BASS TRAIL.

The section of Paleozoic rocks at the Bass trail is given below in two forms—a brief section showing the major subdivisions and a detailed section with comments on the beds.

Section of Paleozoic rocks at Bass trail.

1. General section.

CARBONIFEROUS SYSTEM.

Kaibab limestone (Permian):

A. Gray crystalline limestone, very fossiliferous and somewhat cherty, passing at base and top into alternating beds of very cherty limestone and buff calcareous sandstone; forms cliffs and steep slopes.. 292

B. Buff and reddish fine-grained sandstone, poorly consolidated and irregularly bedded, containing beds of sandy breccia near top; forms slope.................... 136

C. Buff sandstone and limestone in alternating beds, passing at top into massive siliceous limestone; upper portion forms a strong cliff; central portion forms cliffs and ledges; lower portion forms a slope...... 134

562

Coconino sandstone (Permian):

Pale-buff, uniformly fine-grained sandstone characterized by crossbedding on a huge scale; presents the appearance of a single massive bed; forms the strongest and highest cliff in the upper wall of the canyon........ 330

Hermit shale (Permian):

Deep brick-red sandy shale and fine-grained friable sandstone; characterized in upper portion by concretionary structure; beds form slope.................................. 332

Unconformity.

Supai formation (redefined; Permian (?) and Pennsylvanian):

A. Alternating beds of red soft platy sandstone and buff hard cross-bedded sandstone, forming a ledgy slope broken by small cliffs; passing down into reddish or purplish to buff fine-grained cross-bedded sandstone in heavy massive beds, which form a strong cliff........................ 306

B. Alternating beds of red friable shaly sandstone and massive cross-bedded calcareous sandstone including a few thin beds of limestone and a prominent bed of limestone conglomerate and forming a steep ledgy slope broken by small cliffs; passing down into reddish to buff fine-grained calcareous sandstone in heavy beds separated by thin layers of limestone or red shale and forming a strong cliff....... 439

C. Alternating beds of red shale, bluish-gray or purplish-gray limestone, and reddish to buff calcareous cross-bedded sandstone; passing down into alternating beds of red sandy shale and bluish or purplish-gray limestone containing red chert; form ledgy slope broken by small cliffs; outcrops of many beds concealed by talus..

Unconformity (?).

Redwall limestone (redefined and restricted; Mississippian):

A. Bluish-gray massive crystalline limestone in distinct beds, some of which are separated by thin partings of red shale; forms a succession of small cliffs and ledges above sheer cliff of subdivision B......

B. Bluish-gray massive crystalline limestone in beds whose planes of separation are inconspicuous, so that when seen from a distance much of the limestone presents the appearance of a single massive stratum; forms sheerest and most sharply defined cliff in the canyon wall; thickness estimated.......................... ±

C. Brecciated limestone; forms slope under cliff of subdivision B.........................

±

Unconformity (?).

DEVONIAN SYSTEM.

Temple Butte limestone:

Thin-bedded buff and pale-purplish sandy magnesian limestone; more or less blotched and mottled; harder, more massive beds alternate with softer, more conspicuously laminated beds; forms ledgy slope broken by small cliffs.......................................

Unconformity.

CAMBRIAN SYSTEM (TONTO GROUP).

Muav limestone:

A. Buff massive dolomite; forms strong cliff...

B. Buff fine-grained calcareous sandstone; massive at top, thinly laminated and in part micaceous and quartzose near base; forms cliff..............................

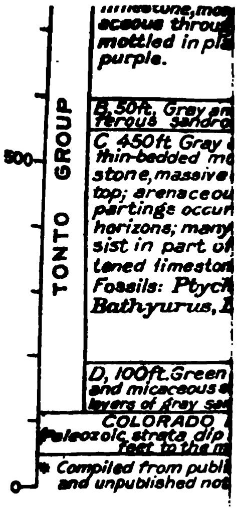
C. Alternating thinly laminated beds of impure mottled limestone, intraformational conglomerate, platy fine-grained micaceous sandstone, and calcareous sandstone; form steep slope........................

D. Gray to buff hard thinly laminated mottled limestone; contains partings of greenish sandy shale for 10 feet at base; forms cliff.

Bright Angel shale:

A. Thin-bedded greenish and buff micaceous shale and sandstone with interbedded layers of impure mottled limestone and glauconitic snuff-brown dolomite at the base; beds form steep slope or weak cliff..

B. Thin-bedded greenish and buff micaceous shale and sandstone with two beds of snuff-brown dolomite and sandstone in the middle portion which form two conspicuous brown cliffs in a long slope made by the shales and sandstones............



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Tapeats sandstone:

A. White cross-bedded sandstone; forms weak cliff	35
B. Chocolate-colored sandstone with partings of shale; forms steep ledgy slope	43
C. Massive chocolate-colored cross-bedded sandstone; forms sheer cliff along rim of Granite Gorge	250
	328
Total thickness of Paleozoic rocks	±4,014

2. Detailed section.

Kaibab limestone:

A. 1. Limestone, buff, compact; effervesces strongly with dilute hydrochloric acid; caps a small cliff on the rim of the canyon at the head of Bass trail. Bass Camp, on the Coconino Plateau, at the head of the trail, is built upon this stratum. Higher beds, which form the surface of the plateau just east of the camp, are not included in this section	2
2. Limestone (for analysis see p. 69), buff, siliceous; texture compact, chalky; contains small cavities lined with tiny crystals	6
3. Sandstone, buff, fine grained, calcareous; effervesces with acid	5
4. Alternating thin beds of variegated chert and fine-grained calcareous sandstone.	25
5. Limestone, gray, crystalline, very cherty, fossiliferous. The chert occurs in nodules and in bands; in places it constitutes half of the rock. Aside from the abundance of chert the limestone resembles No. 6	40
6. Limestone (for analysis see p. 69), gray, hard, crystalline, somewhat cherty, very fossiliferous; effervesces strongly with acid. Beds differ greatly in thickness; some are a few inches thick, others several feet. The chert occurs in scattered nodules and in bands but is not a conspicuous feature of the rock	126
7. Alternating beds of fine-grained buff calcareous sandstone, buff limestone, and chert; form small conspicuous cliff.	10
8. Limestone, gray, hard, crystalline, somewhat cherty, fossiliferous; like No. 6	60
9. Sandstone, lemon-buff, fine-grained, calcareous; bedding irregular, gnarly; forms a gentle slope covered in most places by talus	10
10. Limestone, thin-bedded, very cherty; effervesces with acid. The chert constitutes over half of the rock and occurs in parallel bands whose average thickness is 2 inches	8
	292

[NOTE.—The foregoing section of subdivision A was measured under the rim of the canyon directly in front of Bass Camp, at locality 1, figure 2.]

B. 1. Sandstone, buff, massive, fine-grained, calcareous; effervesces weakly with acid	4
2. Breccia composed chiefly of angular fragments of evenly bedded buff fine-grained sandstone embedded in a matrix of fine lemon-buff sand; contains a few fragments of siliceous limestone. The fragments range in diameter from less than an inch to over 4 feet. The contact of the breccia with the underlying sandstone is wavy and irregular, exhibiting in places inequalities of several feet	17
3. Sandstone, buff, fine-grained, friable. The component grains are quartz, as in other sandstones of the Kaibab, but are very loosely cemented, so that the rock crumbles to sand when struck with the hammer	1
4. Sandstone like No. 3, but bright red	2
5. Buff sandstone like No. 3	8
6. Bright-red sandstone like No. 4	2
7. Lemon-buff sandstone like No. 3	5
8. Bright-red sandstone like No. 4; contains a 1-inch layer of pale-green sandstone in the central portion	7
9. Sandstone, lemon-buff, fine-grained, friable; bedding irregular, gnarly; contact with underlying sandstone slightly wavy and irregular	3
10. Sandstone, bright red, shaly; bedding gnarly; contact with underlying breccia wavy and irregular, exhibiting inequalities of 2 feet or more	3
11. Breccia composed of angular fragments of fine-grained sandstone averaging 4 inches in diameter. Very little matrix between the fragments. The appearance of the rock suggests that it was crushed and shattered after it was deposited. The contact with the underlying sandstone is irregular, exhibiting inequalities of several feet	4
12. Reddish-buff, loosely consolidated fine-grained sandstone in indistinct but fairly even beds, some of which display gnarly structure; forms débris-covered slope; exposures poor. The upper 3 feet of the sandstone is bright red and thinly laminated	12
13. Sandstone like No. 12 but more compact, forming a weak cliff; gnarled and twisted structure very pronounced; color lemon-buff to reddish buff	10
14. Sandstone like No. 12, very soft, forming a gentle slope that is covered nearly everywhere by talus; no good exposures obtainable. Colored white, lemon-buff, greenish, and bright red. In some places the color is in blotches or streaks; in others a single color characterizes each bed	58
	136

[NOTE.—The foregoing section of subdivision B was measured on the northeast side of Fossil Mountain, at locality 2, figure 2.]

C. 1.	Limestone, buff, dense, siliceous; in heavy, massive beds; forms a strong cliff; contains much chert in bands and nodules and many small cavities lined with crystals of quartz or calcite. In appearance the rock suggests silicified chalk. Some beds effervesce weakly with acid	48
2.	Limestone like No. 1 but in thinner beds (1 foot or less) which are separated by thin partings of buff fine-grained shaly sandstone; forms a steep ledgy slope	12
3.	Limestone like No. 1; forms a cliff	16
4.	Shaly sandstone, lemon-buff, soft, thin-bedded, fine-grained; makes alcove under overhanging cliff of No. 3	2
5.	Limestone, buff, in heavy beds with thin sandy partings, not notably siliceous; effervesces strongly with acid; forms cliff	8½
6.	Shaly sandstone like No. 4; makes alcove under overhanging cliff of No. 5	3
7.	Limestone like No. 5 but in thinner beds (1 foot or less); forms slope	11
8.	Limestone, buff, dense, siliceous, in heavy beds; contains numerous crystal-lined cavities apparently formed by the solution of brachiopods; does not effervesce with acid	5½
9.	Limestone like No. 7, in beds separated by very thin partings of sand	5
10.	Sandstone, buff, fine-grained	5
11.	Limestone like No. 7, but in a single bed.	1½
12.	Sandstone, buff, fine-grained	6
13.	Limestone, buff, siliceous, fossiliferous: does not effervesce with acid: contains numerous small cavities lined with calcite crystals	1½
14.	Alternating beds of lemon-buff fine-grained sandstone and buff limestone; beds average 3 inches in thickness	6
15.	Limestone, buff, not notably siliceous; effervesces strongly with acid	½
16.	Sandstone, lemon-buff, fine-grained	2
17.	Sandstone, red, fine-grained. The base of this layer truncates inclined laminae of the underlying Coconino sandstone, which dip 15° S	½
		134

[NOTE.—The foregoing section of subdivision C was measured directly above the point where the Bass trail descends the Coconino sandstone, at locality 3, figure 2.]

Coconino sandstone: Pale-buff fine-grained sandstone, cross-bedded on a huge scale; appears like single massive bed; forms highest cliff in upper wall of canyon. The base of the sandstone is marked by an abrupt change from buff sandstone to underlying red shale, and the contact is an even line. In places the under surface of the sandstone shows impressions of sun cracks. For 25 feet above the base the cross-bedding is on a small scale, and horizontal layers alternate with cross-bedded layers; then the coarse cross-bedding begins and continues upward until the sandstone is truncated by the level base of the Kaibab	330

[NOTE.—The foregoing section of the Coconino sandstone was measured on the Bass trail at the point where the trail descends the sandstone, at locality 3, figure 2. At Mount Huethawali, a mile northwest of this point, the basal layer of the Coconino is massive sandstone 5 feet thick which displays no cross-bedding.]

Hermit shale:

1.	Sandstone, red, soft, fine-grained, massive, with a thin layer of green shale at the top. Exhibits well-marked concretionary structure; the concretions are spheroidal forms which range from half an inch to 4 feet in diameter and consist of the general mass of the rock; in weathering, the rock splits off in concentric shells along the concretionary surfaces	5
2.	Sandstone, fine-grained, massive; resembles the Coconino sandstone in texture and composition but is not cross-bedded; lower half buff; upper half red with buff blotches	6
3.	Concretionary sandstone like No. 1, in massive layers	16
4.	Shale, deep red, thinly laminated, sandy.	24
5.	Beds of soft massive concretionary red sandstone like No. 1 alternating with thinner beds of deep-red shale like No. 4; sandstones and shales not conspicuously different in composition	28
6.	Shale, deep red, sandy	16
7.	Sandstone, pink, hard, very fine grained; contains cracks and cavities filled with crystals of calcite (dog-tooth spar); rock itself does not effervesce with acid; forms small prominent cliff	6
8.	Shale, soft, brick-red, thinly laminated, sandy	28
9.	Sandstone, brick-red, friable, massive; forms weak cliff	2

All underlying beds of shale are like No. 8; all underlying beds of sandstone like No. 9. The beds designated shale and sandstone actually differ little in composition; both consist essentially of sandy mud colored red by a strong ferritic pigment. The beds designated sandstone are massive and relatively compact, as contrasted with the beds designated shale, which are thinly laminated and soft. Both types of rock are friable.

10.	Shale, containing beds of massive friable sandstone near the top	33
11.	Sandstone in massive beds; contains a 1-foot layer of shale in the middle portion; forms weak cliffs	8
12	Shale	11
13.	Sandstone; forms weak cliff	10
14.	Shale	33
15.	Alternating lenticular beds of intraformational conglomerate and red fine-grained sandstone averaging 1 foot in thickness; beds display indistinct sun cracks and rain prints; form weak cliff. The conglomerate consists chiefly of flattened pebbles of fine-grained sandstone or sandy shale less than 1 inch in diameter embedded in a matrix of red sandy mud but contains some nodular or concretionary fragments of limestone	6
16.	Shale	11
17.	Sandstone	3
18.	Shale	40
19.	Sandstone	2
20.	Shale	6
21.	Sandstone; forms weak cliff	5
22.	Shale	16
23.	Sandstone; forms weak cliff	5
24.	Shale	12
		332

[NOTE.—The foregoing section was measured at the east end of Mount Huethawali, about a quarter of a mile northwest of the point where the Bass trail begins to descend into Bass Canyon, at locality 4, figure 2.]

Supai formation:

A. 1.	Sandstone, white, fine-grained, cross-bedded, hard, calcareous; effervesces with acid; contains many cracks lined with calcite; forms a small conspicuous cliff and determines a wide shelf at the general level of the Esplanade platform. At the point where the section was measured the floor of the Esplanade consists in part of this sandstone and in part of knolls of soft red Hermit shale which overlie the sandstone	2½
2.	Sandstone, red, soft, friable, platy, fine-grained; forms a long, gentle slope	16
3.	Sandstone, buff, fine-grained, massive, weathers white; effervesces with acid; unites with underlying bed in forming a cliff	1
4.	Sandstone, pinkish buff, cross-bedded	5½
5.	Red soft platy sandstone like No. 2; forms slope	4½
6.	Massive buff sandstone like No. 3; hard; forms strong cliff	12
7.	Red soft platy sandstone; forms slope	7
8.	Pinkish-buff cross-bedded sandstone like No. 4; forms cliff	5
A. 9.	Soft platy beds of red sandstone alternating with harder, more massive beds; form long ledgy slope	44
10.	Pinkish-buff cross-bedded sandstone; upper surface weathers white; forms cliff.	10½
11.	Red soft platy sandstone; forms waste-covered slope	6
12.	Pinkish-buff cross-bedded sandstone; forms cliff	7
13.	Red soft platy sandstone; forms waste-covered slope	15
14.	Fine-grained sandstone in heavy, massive beds, some of which are separated by thin partings of red soft platy sandstone; cross-bedded throughout; inclined laminae dip south; some beds near the base display an irregular, gnarly structure. The prevailing color of the upper 40 feet of the sandstone is pale brick-red; that of the lower 125 feet ranges from pale purplish to buff. The rock of most beds does not effervesce with acid. A bed of sandy limestone or very calcareous sandstone 2 feet thick occurs 35 feet above the base of the sandstone	165
A. 15.	Conglomerate, composed of subangular fragments of sandstone embedded in a matrix of fine sand of the same composition as the fragments; probably an intraformational conglomerate; displays a rude concretionary structure; fragments weather by splitting off in concentric shells. Many of these shells are embedded in the matrix. The conglomerate varies in thickness and in places is absent; appears to rest upon a slightly uneven surface	0–5
		306

[NOTE.—At the rim of Bass Canyon directly east of Mount Huethawali subdivision A of the Supai is cut by a fault which breaks the strong cliff formed by bed 14. The Bass trail descends the cliff in a shattered zone along the fault. The strata have been displaced about 130 feet by the fault, those on the east side being relatively lowered. In measuring subdivision A at Bass trail it was necessary to divide the section at the fault. Beds 1 to 13 and the upper 40 feet of bed 14 were measured west of the fault, in the slope between the trail and the base of Mount Huethawali, at locality 4, figure 2. Bed 15 and the lower 125 feet of bed 14 were measured on the trail just east of the fault, at locality 5, figure 2. The thickness which I have assigned to bed 14 may be incorrect, because I could not locate equivalent layers in

	the bed on opposite sides of the fault, owing to the homogeneity of the sandstone.]	
B. 1.	Magenta or reddish platy fine-grained shaly calcareous sandstone; effervesces with acid; forms slope	30
2.	Hard massive sandy limestone or very calcareous sandstone; effervesces strongly with acid; unites with underlying bed in forming cliff	2
3.	Gnarly sandstone blotched purplish and buff	5
4.	Red friable sandstone; forms slope	5
5.	Buff cross-bedded calcareous sandstone; forms cliff	10
6.	Red friable shaly sandstone; forms slope.	11
7.	Alternating lenticular beds of conglomerate and fine-grained sandstone, both cross-bedded. Most of the conglomerate consists of well-rounded waterworn pebbles 4 inches or less in diameter embedded in a matrix of red mud and sand; most of the pebbles are bluish-gray or purplish-gray nodular limestone, but some are fine-grained sandstone. Some beds exhibit the peculiar concretionary structure that characterizes bed 15 of subdivision A and consist of subangular fragments of sandstone ranging from less than 1 inch to more than 2 feet in diameter embedded in sand of the same composition as the fragments. The beds of conglomerate and sandstone rest on an uneven surface that exhibits a relief of several feet	28
8.	Red friable shaly sandstone; forms slope.	10
9.	Pinkish-buff cross-bedded calcareous sandstone; unites with underlying bed in forming cliff	18
10.	Pink hard massive sandy limestone or very calcareous sandstone; effervesces strongly with acid	3
11.	Red friable soft sandstone; exhibits concretionary structure; forms slope	8
12.	Buff cross-bedded sandstone; forms cliff.	20
13.	Beds of red shale and soft concretionary calcareous sandstone; form alcove under cliff of No. 12	6
14.	Light brick-red to pinkish-buff, rather soft cross-bedded calcareous sandstone with a few interbedded layers of red shaly sandstone; forms a steep ledgy slope broken by weak cliffs; some beds contain elongated rudely cylindrical or conical forms which are lighter in color than the mass of the rock and in places weather out of the rock. These forms are of various sizes, but most of them are less than 1 inch in diameter. They are undoubtedly organic in origin and may be fucoids	80
B. 15.	Red friable soft thinly laminated sandstone; forms slope	10
16.	Massive sandy limestone or very calcareous sandstone; rests on a slightly uneven wavy surface that truncates inclined laminae of the underlying sandstone; caps cliff formed by the underlying sandstone	3
17.	Buff fine-grained cross-bedded calcareous sandstone; effervesces with acid. The cross-bedding is on a coarse scale; several wedges exceed 30 feet in thickness, and one wedge, exposed at the 4,857-foot bench mark on the Bass trail, is as thick as the entire bed. The Bass trail descends the bed on the inclined laminae of this wedge; inclined laminae in all wedges dip south; curvature of laminae not a conspicuous feature; angular type of cross-bedding appears to prevail; bed forms strong cliff	44
18.	Alternating beds of red friable calcareous sandstone and maroon soft thinly laminated shale; form ledgy slope	28
19.	Light brick-red calcareous sandstone; effervesces strongly with acid; contains elongated cylindrical or conical forms similar to those in bed 14 and numerous obscure small branching forms which may represent either fucoids or worm burrows; makes a ledgy slope	6
20.	Nodular purplish-gray limestone; contains large numbers of the obscure forms noted in bed 19; caps cliff formed by underlying bed	1
21.	Buff cross-bedded calcareous sandstone; like No. 17, but the cross-bedding is on a less coarse scale; forms strong cliff	20
22.	Beds of calcareous sandstone blotched red and buff separated by thin beds of maroon shale which exhibit suncracked surfaces; form alcove under cliff of No. 21. The Bass trail follows this alcove southward to a gulch in which it descends a long rock slide to the base of the Supai	6
23.	Hard pinkish or purplish fine-grained limestone blotched greenish buff; crystalline in places; contains the obscure forms noted in bed 19, also small masses, largely calcite, whose outlines suggest those of brachiopods; with underlying beds forms strong cliff	3
24.	Beds of pinkish fine-grained limestone; form cliff	10
25.	Buff cross-bedded calcareous sandstone like No. 21; forms cliff	35
26.	Red shale; forms small alcove	1
27.	Buff cross-bedded calcareous sandstone like No. 21, divided into two beds by a thin parting of red shale in the center; forms strong cliff. The under	

	surface of the lower sandstone bed exhibits casts of sun cracks at the contact with the underlying shale	34
B. 28.	Maroon shale	½
29.	Massive buff calcareous sandstone; base slightly uneven, wavy	1½
		439
C. 1.	Bluish-gray nodular limestone mixed with red mud which imparts a blotched or mottled appearance to the rock	1
2.	Maroon shale; exhibits concretionary structure; in part brecciated; cracks between fragments infiltrated with red mud; contact with underlying bed uneven, wavy	2–4
3.	Bluish-gray nodular limestone mixed with purplish mud, some of which appears to have been infiltrated along cracks; in part brecciated; contains the obscure forms, probably fucoids, noted in B 14, 20, and other beds	3
	[NOTE.—Beds B 28 and 29 and C 1, 2, and 3 form an alcove under the cliff at the base of subdivision B. The foregoing section, including all of subdivision B and beds 1 to 3 of subdivision C, was measured on or near the Bass trail on the west side of Bass Canyon, at locality 5, figure 2.]	
4.	Slope covered by talus, largely concealing underlying rock. Exposed beds consist of purplish platy calcareous sandstone or sandy limestone, blotched buff, separated by thin layers of red shale	28
5.	Pinkish-buff hard cross-bedded calcareous sandstone; forms cliff	10
6.	Red platy sandy shale	3
7.	Bluish-gray compact crystalline cherty limestone passing downward into hard cross-bedded calcareous sandstone; forms cliff	14
8.	Cross-bedded calcareous sandstone with a 2-inch layer of red shale at the base; forms steep slope	11
9.	Purplish sandy limestone; unites with underlying bed in forming a cliff; contact with underlying bed uneven, exhibiting inequalities of 2 feet in places.	1–3
10.	Hard cross-bedded calcareous sandstone.	2–4
11.	Red soft shaly sandstone; in part cross-bedded; forms a weak cliff	30
12.	Red sandy shale; forms slope	22
13.	Bluish-gray limestone with conspicuous bands of reddish or pink chert; in places the limestone is mixed with reddish or purplish mud, which imparts a mottled appearance to the rock	2
14.	Red sandy shale; forms slope	4
15.	Purplish sandy limestone, in part crystalline; contains a few nodules of red chert; forms slope	5
16.	Red soft fine-grained shaly sandstone in platy beds; forms slope	6
C. 17.	Buff hard fine-grained calcareous sandstone; forms strong cliff	9
18.	Buff fine-grained shaly sandstone; in part conglomerate composed of lumps of chert and buff sandy limestone averaging an inch in diameter; forms slope	5
19.	Red shale; forms slope	12
20.	Bluish-gray limestone containing parallel bands of red chert	2
21.	Purplish massive friable sandy shale speckled with small circular buff spots, passing down into bluish-gray nodular cherty limestone	5
22.	Gnarly nodular bed composed of lumps of purplish sandy shale mixed with purplish mud	1
23.	Conspicuously banded bed composed of bluish-gray limestone and white or red chert; forms strong cliff; the alternating bands of chert and limestone average an inch in thickness; in places the limestone at the summit of the bed is mixed or infiltrated with red mud	10
24.	Gentle slope covered by talus which conceals the bed so completely that no outcrops can be found. The bed appears to be a reddish or purplish soft shale	14
		208

[NOTE.—The foregoing section was measured on the east side of Bass Canyon a quarter of a mile northeast of the point where the Bass trail descends a break in the Redwall cliff at the head of the canyon, at locality 6, figure 2. This break is on the line of a fault along the axis of Bass Canyon. The strata are displaced about 75 feet by the fault, those on the west side of the canyon being relatively lowered.]

Redwall limestone:

A. 1.	Bluish-gray massive limestone in heavy beds; contains a few scattered nodules of chert; forms strong cliff	38
2.	Red, purple, or greenish-buff shale; thinly laminated; forms slope	1
3.	Beds of bluish-gray limestone separated in places by paper-thin partings of red shale; form steep ledgy slope	7
4.	Bluish-gray limestone and red shale in alternating beds which average 1 inch thick; form slope	2
5.	Crystalline limestone; white on freshly broken surfaces; effervesces strongly with acid; contains a few chert nodules and here and there a poorly preserved fossil (see pp. 56–57); forms strong cliff.	6
6.	Bluish-gray crystalline limestone in beds less than 6 inches thick separated by paper-thin partings of reddish or buff	

sandy shale; wastes back in a slope, leaving a ledge at the summit of the sheer cliff of subdivision B.......... 8

62

[NOTE.—The foregoing section was measured on the east side of Bass Canyon directly under the place where subdivision C of the Supai was measured, at locality 6, figure 2.]

B. Massive crystalline limestone forming a sheer high cliff; upper portion heavily and obscurely bedded; middle portion distinctly bedded and containing many thin interbedded layers of chert and sand; lower portion heavily bedded and magnesian. Most beds contain scattered nodules of chert. Many contain coarse crystals of calcite; some of the calcite lines cavities; some of it occurs in large masses in the rock; some of it forms beds several inches to a foot thick. Intercalated layers of sand are commonly less than a foot thick, are loosely cemented, and exhibit gnarly structure; most of them rest on irregular, wavy surfaces. In many places the limestone cliff is stained pink by ferritic pigment washed over it from overlying red shales; unstained surfaces of the limestone weather bluish gray; freshly broken surfaces are gray, buff, or white. Subdivision B is rudely divisible into three members, as follows:

1. Obscurely bedded limestone, most of which is in heavy beds; beds differ greatly in thickness, some being over 20 feet thick, others only a few inches; most of the limestone is finely crystalline, light gray or white on freshly broken surfaces, and very pure (for analysis see p. 55); effervesces strongly with acid. Contains a few thin beds of sand, some chert, and much calcite in coarse crystals. Surface of limestone at top of cliff exhibits very poorly preserved fossils. Thickness estimated.. ±200
2. Distinctly bedded limestone in rather uniform beds, most of which do not exceed 5 feet in thickness; limestone beds alternate with thin layers of chert or sand; effervesce strongly with acid; some beds are very fossiliferous, but fossils are poorly preserved. Owing to its laminated character this member is less resistant to erosion and recedes faster than the overlying heavy-bedded limestone, so that in many places it is overhung by the overlying member. This difference in erosion determines the formation of great niches or alcoves in the Redwall cliff. Thickness estimated............................ ±220

B. 3. Heavy-bedded magnesian limestone; chemical composition near that of dolomite (see analysis, p. 55); does not effervesce freely with acid; some beds are separated by thin layers of loosely consolidated sandstone; under Wallace Butte the limestone rests on a layer of loose gnarly sandstone 1 foot thick. Thickness estimated......... ±80

±500

[NOTE.—The foregoing section of subdivision B was examined along the Bass trail, at locality 6, figure 2. The thickness assigned to subdivision B is the thickness of its cliff under Wallace Butte in Bass Canyon as measured on the topographic map of the Shinumo quadrangle.]

C. Brecciated limestone composed of subangular fragments of limestone 6 inches or less in diameter embedded in a matrix of yellowish or purplish sand; in places passes into gnarly calcareous sandstone or into limestone containing irregular masses of yellowish or purplish sand; forms steep slope or weak cliff under sheer cliff of subdivision B. In places the base of this curious bed is uneven; in places the summit is uneven. Average thickness............ 8

[NOTE.—The foregoing section of subdivision C was measured under Wallace Butte on the west side of Bass Canyon, at locality 7, figure 2.]

Temple Butte limestone:

1. Thinly laminated sandy magnesian limestone in rubbly beds mottled pale purplish or buff; effervesces feebly with acid; soft; forms slope. Some mottled beds resemble beds in the Muav limestone that have been bored by worms.......................... 10
2. Limestone like No. 1 but harder and more massive; forms small cliff........ 3
3. Thin beds of limestone like No. 1 alternating with thin beds of intraformational conglomerate composed largely of flattened pebbles of limestone; form slope.............................. 5½
4. Limestone like No. 2; forms cliff......... 4½
5. Limestone like No. 1; forms slope........ 21
6. Limestone like No. 2; forms small cliff... 1
7. Limestone like No. 1; forms slope........ 6
8. Limestone like No. 2; forms strong cliff.. 3
9. Limestone like No. 2; forms cliff......... 3

10. Massive bed of purplish crystalline magnesian limestone; forms cliff..........	1
11. Limestone like No. 2; forms cliff; surface exhibits cross sections of poorly preserved cup corals (?)................	3
12. Limestone like No. 1; forms slope........	6
13. Limestone like No. 2; forms cliff.........	3
14. Limestone like No. 1 (for analysis see p. 52); very soft; forms gentle slope above strong cliff at top of underlying Muav limestone......................	5
	75

[NOTE.—The foregoing section was measured under Wallace Butte on the west side of Bass Canyon, at locality 7, figure 2. At this locality the contact between bed 14 and the underlying Muav limestone exhibits no irregularity in a distance of 1,000 feet, and the bed appears to rest conformably upon the Muav limestone, but in Ruby Canyon, 2 miles southeast of Bass Canyon, the contact is very uneven, exhibits vertical inequalities of 40 feet or more in horizontal distances of a few hundred feet, and clearly represents a strong line of erosion.]

Muav limestone:

A. 1. Buff hard massive crystalline dolomite in heavy beds (for analysis see p. —); does not effervesce with acid; forms cliff. At one place on the east side of Bass Cañyon the thickness of the dolomite is 25 feet less than it is under Wallace Butte, on the west side of the canyon, where this section was measured. Apparently a depression in the surface of erosion at the top of the Muav exists at that point, but the feature is obscure because fans of talus mask the strata for some distance on both sides of the exposure............................	52
2. Poorly exposed bed of soft rock, apparently greenish-buff shaly sandstone; determines a narrow ledge which breaks the cliff formed by Nos. 1 and 3	1
3. Buff hard massive crystalline dolomite in heavy beds; probably originally a very fine calcareous sand; exhibits indistinct cross-bedding; forms cliff..	10
	63

B. Pale-buff to greenish-buff fine-grained calcareous sandstone blotched purplish in places; beds differ greatly in thickness, ranging from a fraction of an inch to 6 feet; some beds are massive; others thinly laminated; some exhibit indistinct cross-bedding; massive beds predominate in upper part of the subdivision, thinly laminated beds in lower part. The sand is prevailingly calcareous; many beds effervesce readily with acid, and specimens of these beds tested in the Survey laboratory show little magnesium; the rock in a few massive beds, however, resembles the overlying dolomite (A 3), effervesces feebly, and is magnesian. Some of the sand is finely micaceous, and some is finely quartzose. A number of the beds contain tiny greenish grains of glauconite. Some beds are worm-bored. Beds of intraformational conglomerate composed of flattened pebbles of calcareous sandstone occur at several horizons. A thin layer of reddish sandy shale associated with a bed of intraformational conglomerate, 40 feet above the base of the subdivision, exhibits well-preserved sun cracks. The laminated beds at the base of the subdivision consist chiefly of platy micaceous sandstone which does not effervesce with acid..........	72

C. 1. Thin layers of calcareous intraformational conglomerate, platy greenish micaceous sandstone, greenish micaceous shale, and buff cross-bedded calcareous sandstone in countless alternations. The intraformational conglomerate consists essentially of small flattened pebbles of gray and buff mottled limestone like that of subdivision D and buff calcareous sandstone; all parts of it effervesce with acid. The pebbles have rounded edges and are cemented together by fine-grained calcareous micaceous sandy mud or by calcium carbonate. Most of the rock contains worm burrows and fucoidal casts filled with buff sand. Beds range in thickness from less than half an inch to 6 inches and are lenticular; many wedge out in distances of 100 feet; some pass horizontally into cross-bedded sandstone; small local unconformities are common. Some beds are blotched purplish. Many layers of the micaceous sandstone and shale are as thin as cardboard. Much of the calcareous sandstone consists almost entirely of calcium carbonate and might be classed as limestone, but the cross-bedding reveals its clastic origin. In most places bed 1 and the underlying beds 2 to 7 form cliffs.....	8
2. Gray and buff mottled limestone like subdivision D, but in beds separated by partings of buff sand as thin as cardboard...............................	2
3. Intraformational conglomerate like that in bed 1..............................	½

C. 4. Mottled limestone in thin beds with sandy partings	1
5. Intraformational conglomerate	½
6. Mottled limestone in thin beds with sandy partings	2
7. Intraformational conglomerate	1
8. Beds of intraformational conglomerate averaging 6 inches thick alternating with thin beds of gray and buff mottled limestone; form steep cliff	32
9. Hard massive bed of intraformational conglomerate; forms small cliff	1
10. Beds like No. 8 but containing numerous very thin partings of fine micaceous and calcareous buff sandstone near base; form slope	43
11. Buff fine-grained crystalline limestone, weathering snuff-brown: effervesces strongly with acid; exhibits indistinct cross-bedding and is probably composed of fine calcareous sand; hard; forms small conspicuous brown cliff and is a very persistent bed in the western part of the Kaibab division, being traceable throughout the Shinumo quadrangle	8
12. Beds of gray and buff mottled limestone and intraformational conglomerate in countless alternations; contain many thin partings of fine-grained buff or greenish-buff micaceous and calcareous sand; worm borings and fucoidal casts abundant; beds form slope. In general the beds of mottled limestone contain more buff fine sandy material than those which constitute the underlying subdivision D, although some are comparatively pure. An analysis of a sample from a typical bed of the impure mottled limestone 35 feet below the top of No. 12 in Turquoise Canyon (see p. 43) shows that about a quarter of the rock consists of insoluble material, probably silica, whereas the remainder consists essentially of calcium carbonate with only a trace of magnesium. The beds of intraformational conglomerate effervesce as freely with acid as the mottled limestone; tests indicate that they are not magnesian and that they probably differ little in chemical composition from the impure mottled limestone	142
D. Gray and buff hard thin-bedded mottled limestone; effervesces with acid; forms strong cliff. The color of the pure limestone is gray to bluish gray, but many beds contain a varying amount of buff fine calcareous, more or less micaceous sand or sandy mud which imparts a mottled appearance to the rock. The limestone contains numerous fucoidal or coralloid forms, most of which are composed of the buff sandy material, but some of which are composed of the limestone itself. Probably most of these forms are filled worm burrows. At the base of the subdivision thin layers of platy buff sandstone and greenish shale alternate with the mottled limestone for about 10 feet	97

[NOTE.—The foregoing section of the Muav limestone was measured under Wallace Butte on the west side of Bass Canyon, at locality 7, figure 2.]

Bright Angel shale:

A. Beds of greenish soft micaceous shale in paper-thin laminae alternating with beds of buff platy hard fine-grained micaceous quartzose sandstone which range in thickness from a quarter of an inch to an inch; worm borings abundant; beds form alcove under cliff of subdivision D of Muav limestone	10
2. Alternating thin beds of worm-worked buff calcareous sandstone and greenish-buff micaceous sandy shale; form steep slope	21
3. Thin beds of buff sandstone, greenish shale, mottled limestone like subdivision D of the Muav, and snuff-brown dolomite in countless alternations; most beds less than 1 inch thick; worm borings abundant; many layers of sandstone ripple-marked; beds form weak cliff	26
4. Snuff-brown hard crystalline glauconitic dolomite forming small cliff. The glauconite appears to constitute from a quarter to a half of the rock and occurs in tiny rounded grains scattered through a groundmass of crystalline dolomite. Although the rock is crystalline, weathered surfaces exhibit distinct cross-bedding, showing that the rock is of classic origin	1
	58
B. Thin beds of buff platy quartzitic sandstone and greenish micaceous shale in countless alternations; glauconite very abundant at top; a 4-inch bed of magenta sandstone containing ground-up remains of linguloid brachiopods and much glauconite occurs 7 feet above the base; neither sandstone nor shale effervesces with acid; beds form slope. The sandstone beds average a quarter of an inch in thickness and consist chiefly of tiny transparent grains of quartz but contain small flakes of muscovite and scattered grains of glauconite; most beds speckled with small reddish or brownish spots; ripple marks and worm burrows abundant. Much of the shale is in paper-thin laminae whose surfaces exhibit a satiny luster imparted by innumerable tiny flakes of muscovite; many outcrops are	

covered with a whitish saline efflorescence	17
B. 2. Magenta to dark-green glauconitic sandrock passing at top into a 6-inch bed of snuff-brown glauconitic crystalline dolomite; forms weak cliff. In places the sandrock and dolomite pass into intraformational conglomerate containing broken shells of linguloid brachiopods. The dark-green phase of the sandrock owes its color to glauconite; the magenta phase owes its color to ferritic cement, largely hematite, which makes the rock relatively heavy	2½
3. Buff platy sandstone and greenish shale like No. 1; beds form slope	60
4. Dark magenta cross-bedded sandstone containing much glauconite; forms small cliff	1½
5. Buff platy sandstone and greenish shale like No. 1; glauconite very abundant; beds form slope	38
6. Thin beds of snuff-brown to buff fine-grained calcareous sandstone forming the upper of the two prominent brown cliffs in the middle of the Bright Angel shale; thin platy beds of finely crystalline buff dolomite containing shells of linguloid brachiopods occur in the upper 5 feet	13
7. Buff platy sandstone and greenish shale like No. 1; beds form slope and ledge between the cliffs of Nos. 6 and 8; some thin beds consist almost wholly of glauconite	38
8. Heavy beds of snuff-brown massive crystalline dolomite (for analysis see p. 40), 7 feet; passing down into beds of buff fine-grained cross-bedded glauconitic sandstone, 5 feet; the dolomite and sandstone form the lower of the two brown cliffs in the middle of the Bright Angel shale	12
9. Buff platy sandstone and greenish shale like No. 1; a 4-inch bed of fossiliferous magenta glauconitic sandstone occurs 34 feet above the base; beds form gentle slope	66
10. Fossiliferous magenta glauconitic sandstone, 2 feet, passing up into buff platy quartzitic sandstone, 2 feet; beds form a weak cliff	4
11. Buff platy sandstone and greenish shale like No. 1 but containing more platy sandstone in proportion to the shale, so that the beds form a somewhat steeper slope. Beds of magenta sandstone containing hematite, glauconite, and ground-up shells of linguloid brachiopods occur at 16, 23, 32, 34, and 66 feet above the base; these beds range in thickness from 1 to 4 inches; part of the hematite occurs as cement between the sand grains; part of it coats the sand grains in tiny concentric layers, giving the rock an oolitic appearance; most of the sand grains are quartz or glauconite but some are pink feldspar; some of the ferritic beds resemble Clinton iron ore	83
	333
[NOTE.—The foregoing section of the Bright Angel shale was measured on the east side of Bass Canyon about half a mile south of Bedrock Tank, at locality 8, figure 2.]	
Tapeats sandstone:	
A. White to greenish-white cross-bedded sandstone in rather thick beds composed chiefly of clean quartz sand; contains a few lenses of soft greenish sandy shale; lenses of hard sandstone alternate with lenses of softer sandstone which etch out and form alcoves and shelves. The sandstone is speckled with small magenta or brownish spots which represent segregations of ferritic material	35
B. Chocolate-colored sandstone in rather thin beds separated by layers of greenish or brownish shale; contains some cross-bedded layers, but evenly bedded layers predominate	43
C. Hard chocolate-colored cross-bedded sandstone; commonly a pebbly grit composed chiefly of quartz sand; many beds are indurated to quartzite; small yellow rounded quartz pebbles, the largest the size of peas, are a characteristic constituent; thin lenses of shale are rather abundant in the upper half of the member; the lenses of the shale or softer sandstone etch out and form alcoves and shelves. In many places the lower half of the cliff is incrusted with salt (sodium chloride), and in some protected situations the salt forms stalactites. Lenticular beds of conglomerate from 1 to 15 feet thick occur throughout the sandstone but are more abundant in the basal portion. Some conglomerate beds consist of unassorted angular fragments of the underlying rocks; others consist chiefly of rounded pebbles of quartz. In some places where the sandstone rests against hills of pre-Cambrian rock, beds of coarse breccia occur in the sandstone at the base of the pre-Cambrian hills; one of these beds of breccia exposed in a cliff on the north side of Colorado River, half a mile southeast of the mouth of Bass Canyon, contains blocks of pre-Cambrian quartzite 30 feet in diameter. The Tapeats sandstone rests on an eroded surface which in some places in	

the Shinumo quadrangle exhibits a relief of nearly 600 feet; consequently the thickness of subdivision C at any point depends on the topography of the underlying surface. Near the mouth of Bass Canyon, where this section was measured, subdivision C is 328 feet thick, whereas a mile to the northeast, under Dox Castle, it is absent. The thickness of 250 feet which I have assigned to the subdivision represents approximately the average thickness in Bass Canyon	±250
[NOTE.—The foregoing section of the Tapeats sandstone was measured west of the mouth of Bass Canyon, at the point where a trail leading from Bedrock Tank to Copper Canyon ascends a break in the cliff formed by the sandstone, at locality 9, figure 2.]	
Total thickness of Paleozoic beds	±4014

THE PALEOZOIC ROCKS.

CAMBRIAN SYSTEM.

TONTO GROUP.

GENERAL FEATURES.

In the region about Bass Canyon the Tonto group is a series of conformable strata about 1,200 feet thick which lies at the base of the Paleozoic and is separated from underlying pre-Cambrian rocks and from overlying Devonian and Carboniferous rocks by unconformities of erosion. In lithology the group as a whole exhibits a passage upward from sandstone to limestone, roughly in three stages. The strata at the base of the group are sandstones; those in the middle portion are chiefly fine-grained sandstones and sandy shales; and those in the upper portion are more or less sandy calcareous rocks which pass at the top into magnesian limestone. These three lithologic stages afford a natural basis for dividing the group into formations. Accordingly, in a former report describing the region about Bass Canyon[7] I proposed a threefold division of the Tonto group and used the names Tapeats sandstone, Bright Angel shale, and Muav limestone to designate the formations. The name Tapeats sandstone is applied to the sandstone at the base of the group, the name Bright Angel shale to the sandstone and shale of the middle portion, and the name Muav limestone to the more or less calcareous strata that constitute the upper portion. Walcott had previously adopted a similar threefold division of the Tonto. He states,[8] "I find among my notes made after the trip to the Grand Canyon in 1901 * * * that I had given names to the three divisions of the Tonto along the same lines that you have, so I can readily agree with your present subdivisions and nomenclature."

At Bass Canyon the three formations are distinct in lithology and in topographic expression, but farther southeast, in the region between the Hermit and Grand View trails, where most visitors see the Grand Canyon, the boundary between the Muav limestone and the Bright Angel shale is indefinite, and the two formations do not appear at first sight to differ conspicuously, whereas the Tapeats sandstone and the Bright Angel shale preserve their distinctive characters and can be distinguished readily. Some uncertainty has therefore existed as to the limits of the Muav limestone in the more frequented part of the Grand Canyon, and the propriety of a threefold division of the Tonto has been questioned.

To determine whether the Muav limestone as defined at Bass Canyon is actually traceable into the region between the Hermit and Grand View trails, I have measured six sections of the Tonto group at different points in the south wall of the Grand Canyon. These sections, spaced from 3 to 8 miles apart, carry the lithology of the Tonto through a distance of about 28 miles southeastward—from Garnet Canyon, 3 miles west of Bass Canyon, to Cottonwood Creek, in the Grand View region—and, in connection with a section measured by Walcott at Nunkoweap Valley, 15 miles north of Cottonwood Creek, carry it practically through the Kaibab division of the Grand Canyon. These seven sections are shown on Plate XX. In addition to recording the Tonto lithology I have represented the unconformity at the summit of the Tonto by indicating diagrammatically the amount of relief which the eroded surface exhibits at each locality, and, where the beds that lie between the unconformity and the Redwall cliff were accessible, I have recorded their character and succession. Owing to lack of space in the drawing I have presented only a brief description of the lithology of each section. The Bass Canyon section is given in

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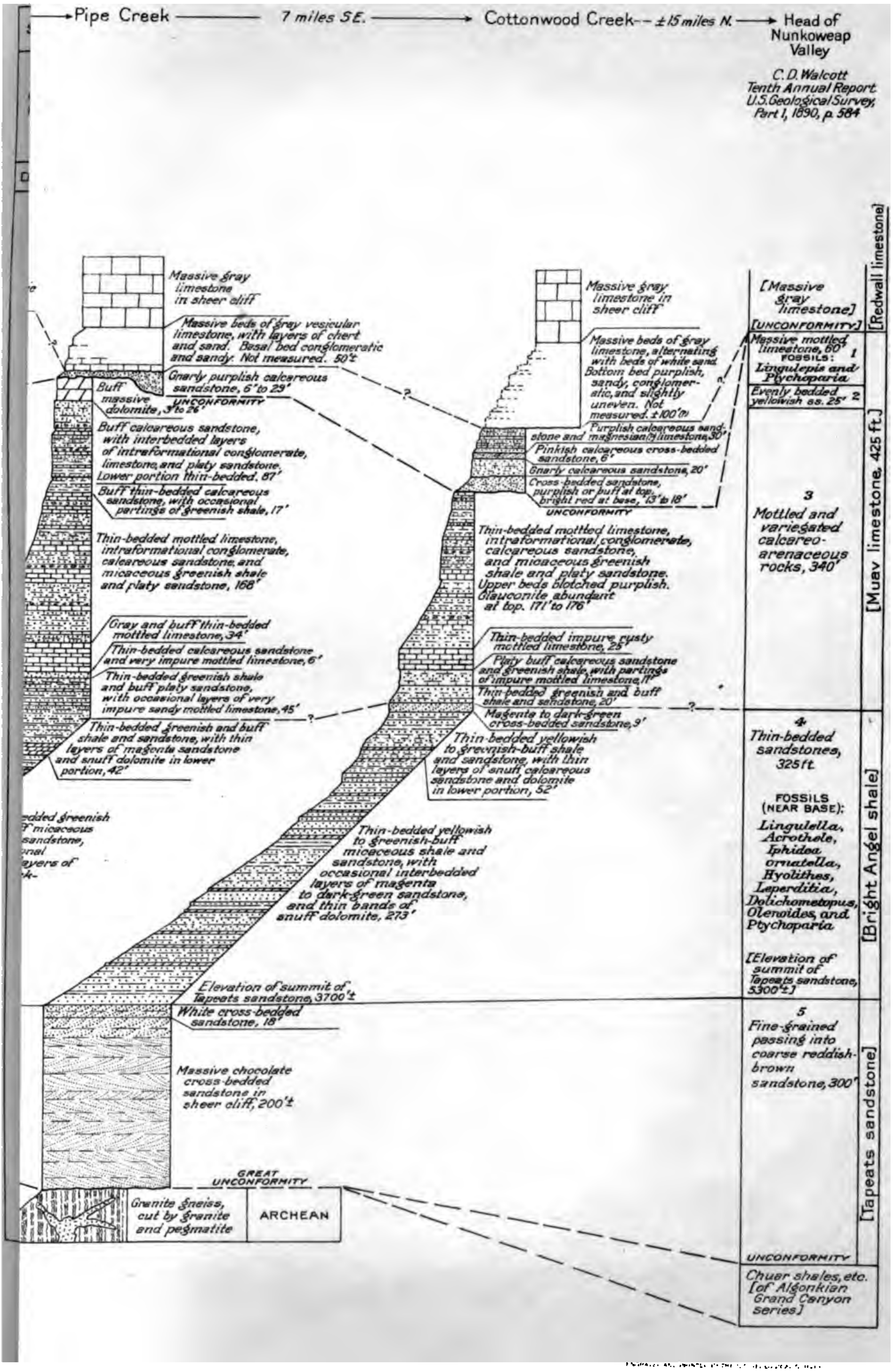
[7] Noble, L. F., The Shinumo quadrangle, Grand Canyon district, Ariz.: U. S. Geol. Survey Bull. 549, p. 61, 1914.

[8] Walcott, C. D., personal communication.


Pipe Creek
7 miles SE.
Cottonwood Creek
±15 miles N.
Head of Nunkoweap Valley
C. D. Walcott Tenth Annual Report U.S. Geological Survey, Part I, 1890, p. 584
Massive gray limestone in sheer cliff
Massive beds of gray vesicular limestone, with layers of chert and sand. Basal bed conglomeratic and sandy. Not measured. 50'±
Gnarly purplish calcareous sandstone, 6" to 29'
Buff massive dolomite, 3' to 26'
UNCONFORMITY
Buff calcareous sandstone, with interbedded layers of intraformational conglomerate, limestone, and platy sandstone. Lower portion thin-bedded. 87'
Buff thin-bedded calcareous sandstone, with occasional partings of greenish shale, 17'
Thin-bedded mottled limestone, intraformational conglomerate, calcareous sandstone, and micaceous greenish shale and platy sandstone, 168'
Gray and buff thin-bedded mottled limestone, 34'
Thin-bedded calcareous sandstone and very impure mottled limestone, 6'
Thin-bedded greenish shale and buff platy sandstone, with occasional layers of very impure sandy mottled limestone, 45'
?
Thin-bedded greenish and buff shale and sandstone, with thin layers of magenta sandstone and snuff dolomite in lower portion, 42'
edded greenish
f micaceous
sandstone,
onal
ayers of
k-
Massive gray limestone in sheer cliff
Massive beds of gray limestone, alternating with beds of white sand. Bottom bed purplish, sandy, conglomeratic, and slightly uneven. Not measured. ±100'(?)
Purplish calcareous sandstone and magnesian(?) limestone, 30'
Pinkish calcareous cross-bedded sandstone, 6'
Gnarly calcareous sandstone, 20'
Cross-bedded sandstone, purplish or buff at top, bright red at base, 13' to 18'
UNCONFORMITY
Thin-bedded mottled limestone, intraformational conglomerate, calcareous sandstone, and micaceous greenish shale and platy sandstone. Upper beds blotched purplish. Glauconite abundant at top. 171' to 176'
Thin-bedded impure rusty mottled limestone, 25'
Platy buff calcareous sandstone and greenish shale, with partings of impure mottled limestone, 11'
Thin-bedded greenish and buff shale and sandstone, 20'
Magenta to dark-green cross-bedded sandstone, 9'
Thin-bedded yellowish to greenish-buff shale and sandstone, with thin layers of snuff calcareous sandstone and dolomite in lower portion, 52'
Thin-bedded yellowish to greenish-buff micaceous shale and sandstone, with occasional interbedded layers of magenta to dark-green sandstone, and thin bands of snuff dolomite, 273'
Elevation of summit of Tapeats sandstone, 3700'±
White cross-bedded sandstone, 18'
Massive chocolate cross-bedded sandstone in sheer cliff, 200'±
GREAT UNCONFORMITY
Granite gneiss, cut by granite and pegmatite
ARCHEAN
[Massive gray limestone]
[UNCONFORMITY]
[Redwall limestone]
Massive mottled limestone, 60'
1
FOSSILS:
Lingulepis and Ptychoparia
Evenly bedded yellowish ss. 25'
2
3
Mottled and variegated calcareo-arenaceous rocks, 340'
[Muav limestone, 425 ft.]
4
Thin-bedded sandstones, 325 ft.
FOSSILS (NEAR BASE):
Lingulella, Acrothele, Iphidea ornatella, Hyolithes, Leperditia, Dolichometopus, Olenoides, and Ptychoparia
[Elevation of summit of Tapeats sandstone, 5300'±]
[Bright Angel shale]
5
Fine-grained passing into coarse reddish-brown sandstone, 300'
[Tapeats sandstone]
UNCONFORMITY
Chuar shales, etc. [of Algonkian Grand Canyon series]

ONWOOD CREEK

detail in the present report (see pp. 26–36), but an account of the detailed lithology of the other sections is beyond the scope of this paper and will be reserved for another report. In all six sections the Bright Angel shale and Muav limestone were measured by hand level and the Tapeats sandstone was measured by aneroid barometer except at Bass Canyon, where the level was used. The sections at Garnet Canyon, Bass Canyon, Slate Creek, and Hermit Creek are believed to be more accurate than those at Pipe and Cottonwood creeks because they were checked over in detail during a subsequent field trip, whereas the sections at Pipe and Cottonwood creeks were not reviewed.

These sections show that the Muav limestone as defined at Bass Canyon is represented by equivalent beds throughout the Kaibab division, and that the principal subdivisions of the Bass Canyon section preserve enough of their original character to be recognizable in the other localities, although large parts of the formation become sandy southeast of Bass Canyon, the proportion of sandstone to limestone increasing southeastward. The appearance of sandy material in the lower part of the Muav southeast of Bass Canyon makes it increasingly difficult to define exactly the boundary between the Bright Angel shale and the Muav limestone in that direction, as will be shown.

When I proposed the name Muav limestone I used the term "limestone" because in the type locality, near Bass Canyon, the formation as a whole contains more limestone than sandstone and shale. Inasmuch as the formation becomes increasingly sandy southeast of Bass Canyon it may be advisable eventually to change the name to Muav formation, but it seems best to retain the name Muav limestone for the present, until the formation has been studied over a wider area than that covered in this report.

TAPEATS SANDSTONE.

Character.—The Tapeats sandstone is essentially a medium to rather coarse sandstone, grading here and there into a pebbly grit and including beds of conglomerate and shale. The prevailing color is chocolate-brown, although many beds are buff or greenish buff and some beds are pale greenish white. The conglomerate forms lenticular beds that may occur at any horizon in the formation but are more abundant near the base, where as a rule the conglomerate is arkosic and consists of poorly assorted fragments of underlying rocks. Some of the conglomerate, however, is well assorted and consists of rounded pebbles of quartz. Most of the shale occurs above the middle of the formation in thin lenses between layers of sandstone. In general the component materials of the formation become finer and better assorted toward the top. The uppermost beds at Bass Canyon are clean white or greenish-white cross-bedded sandstone.

Among the distinctive features of the formation are hardness, which causes it to weather into sheer cliffs, prevailing chocolate color, cross-bedding, and a rather coarse horizontal banding due to the fact that the beds form elongated horizontal lenses and differ in texture and hardness. Here and there beds of shale alternate with beds of sandstone, and at most places the sandstone itself, although prevailingly hard, exhibits wide differences in induration. A bed of sandstone which in one place is cemented into compact vitreous quartzite may be poorly consolidated a few hundred feet away. Vertically beds of hard quartzitic sandstone succeed beds of softer sandstone in countless alternations. Erosion etches the bands of softer material into long low alcoves overhung by shelves of harder rock. These shelves and alcoves appear on every outcrop of the Tapeats sandstone and are particularly conspicuous in its great cliff, which is furrowed by tier upon tier of them. (See Pl. XXI, *A*.) One who is traveling through the canyon along the Tonto platform, or "lower plateau," soon learns to appreciate the shelter which these "Tonto shelves" afford and usually selects them for his camp. Indeed, the selection is almost compulsory, for in most tributary canyons water comes to the surface in the dry watercourses only at the point where the stream channel crosses the summit of the Tapeats sandstone.

Another distinctive feature of the sandstone is the occurrence in many beds of numerous small yellow rounded quartz pebbles, the largest of which are the size of peas. Worm markings are common in the white sandstone at the top of the Tapeats and occur here and there in the underlying chocolate-colored beds. I have observed ripple marks at a few places in the formation and sun cracks at one place. Glauconite occurs sparingly in scattered grains in some beds.

In many places in the Kaibab division the Tapeats cliff is incrusted with salt. Commonly the deposits are less than an inch thick, but some of them may cover hundreds of square feet. A sample from one of these salt deposits in Garnet Canyon was tested in the laboratory of the Survey and is reported to consist essentially of sodium chloride. A spring that issues from the contact between the Tapeats sandstone and the underlying crystalline rocks at a point about half a mile west of Garnet Canyon yields a heavy brine. Other brine springs issue from this contact at several places in the Kaibab division. The water of the intermittent stream in Garnet Canyon is potable above the middle of the Tapeats sandstone, but below the middle of the sandstone it is too salty to drink. These occurrences indicate that the Tapeats sandstone contains salt, although no beds of salt have been found within the sandstone. Perhaps a small amount of salt is widely distributed in the sandstone but has escaped observation because it is not concentrated in beds. Inasmuch as the Tapeats is a marine deposit the salt is probably an original constituent of the sandstone.

The Tapeats sandstone exhibits little variation from place to place in lithology or in general appearance and is readily identifiable in all parts of the Kaibab division.

Stratigraphic relations.—Both base and summit are well defined, the base by a great angular unconformity that truncates underlying pre-Cambrian rocks and the summit by a rather abrupt change from coarsely banded white cross-bedded sandstone at the top of the Tapeats to thinly laminated even-bedded sandstone and sandy shale at the base of the overlying Bright Angel shale.

Subdivisions.—At Bass Canyon the formation is rudely divisible into three parts. (See Pl. XX.) Subdivision A, at the top of the formation, consists of white cross-bedded sandstone which includes a few layers of greenish shale. Subdivision B, beneath A, consists of evenly bedded chocolate-colored sandstone with partings of shale. Subdivision C, at the base, consists of chocolate-colored cross-bedded sandstone and constitutes by far the greater part of the formation. As the Tapeats sandstone is traced southeastward from Bass Canyon, subdivision A decreases in thickness and becomes more and more like C in lithologic character until it is practically indistinguishable from C, so that in the three easternmost sections shown on Plate XX the formation is divisible into only two parts and consists essentially of chocolate-colored cross-bedded sandstone capped by white cross-bedded sandstone. Where hills of pre-Cambrian rock project into the Tapeats sandstone, beds of coarse conglomerate may appear at any horizon in the sandstone where it rests against their steeper slopes, but these conglomerates are local in extent and do not persist many hundreds of feet.

Thickness.—The Tapeats sandstone varies irregularly in thickness from place to place, but the variations have no ultimate stratigraphic significance because the sandstone was deposited upon a surface which, although remarkably even when considered in relation to its vast horizontal extent, is uneven in detail, exhibiting at some places a relief of 600 feet. Thus at the point where the section at Bass Canyon was measured the sandstone attains a thickness of 328 feet, whereas the average thickness in Bass Canyon does not exceed 250 feet; and a mile away, on the north side of Colorado River, where a hill of hard pre-Cambrian strata rises several hundred feet above the general level of the pre-Cambrian surface, the sandstone was not deposited. The thickness assigned to the sandstone at Bass Canyon is exceptional. Perhaps 200 feet would be a fair estimate of the average maximum thickness in the Kaibab division.

Fossils.—No fossils have been found in the Tapeats sandstone except near the top. Schuchert[9] has noted fragments of an obolid shell in the white cross-bedded sandstone at the top of the formation near Hermit Creek. Walcott[10] reports the following fauna "in the Tapeats sandstone about 300 feet above its base at the head of Nunkoweap Valley":

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[9] Schuchert, Charles, The Cambrian of the Grand Canyon of Arizona: Am. Jour. Sci., 4th ser., vol. 45, p. 365, 1918.

[10] Walcott, C. D., Cambrian geology and paleontology: Smithsonian Misc. Coll., vol. 64, No. 5, pp. 373, 374, 1916.

Dolichometopus tontoensis.
Micromitra pealei.
Micromitra (Paterina) crenistria.
Micromitra (Paterina) superba.
Micromitra (Iphidella) pannula.
Obolus zetus.
Obolus (Westonia) chuarensis.
Obolus (Westonia) englyphus.
Lingulella lineolata.
Lingulella perattenuata.
Billingsella obscura.
Alokistocare althea.

According to Walcott the thickness of the Tapeats sandstone at Nunkoweap Valley is 300 feet (see Pl. XX), so that the beds from which he obtained this fauna must lie at the very top of the formation. The age of the fauna is stated to be Middle Cambrian. Practically all the forms listed occur also in the Bright Angel shale.

The age of the summit beds of the Tapeats sandstone is therefore Middle Cambrian. Inasmuch as the formation appears to have been deposited continuously, as is indicated by its homogeneous character, and to have accumulated rapidly, as is indicated by its relatively coarse cross-bedded structure, it is not likely that any part of it is older than Middle Cambrian.

BRIGHT ANGEL SHALE.

Character.—The chief constituent of the Bright Angel shale is fine-grained quartzose micaceous sand, which forms innumerable platy beds mostly less than a quarter of an inch thick. Many beds of sandstone are separated by partings of micaceous sandy shale, and at some horizons the sandstone and shale are associated with dolomitic limestone or with cross-bedded glauconitic sandstone.

The distinctive features of the formation are thin, platy lamination, a prevailingly dull greenish-buff color, the occurrence of glauconite in many beds, and the abundance of worm-markings and fucoidal casts. Many beds are ripple-marked. Shells of obolid or linguloid brachiopods are abundant at many horizons, and most of the shells are broken and worn, showing marks of grinding and attrition. The ripple marks indicate that the strata were deposited in shallow water, and the broken shells indicate that the deposits were subjected to repeated pounding by waves.

The formation as a whole is the least resistant to erosion of all the formations in the canyon wall. It makes a more or less continuous slope, which at most places has retreated far back from the summit of the Tapeats cliff, leaving the so-called "lower plateau," or Tonto platform. It owes its weakness to the alternations of shale and sandstone and to the thin platy lamination of the beds. Actually most of the platy sandstone is well indurated, and some of it is as compact as quartzite.

Glauconite is decidedly more abundant in the Bright Angel shale than in the other two formations of the Tonto group. It occurs rather sparingly in most beds in tiny grains scattered through the rock but is widely distributed in the formation, both vertically and horizontally. Apparently no beds consist entirely of glauconite, but an examination of the formation anywhere in the Kaibab division of the Grand Canyon will disclose a few beds several inches thick in which nearly half of the rock is glauconite and many beds in which the grains are sufficiently abundant to impart a greenish tinge to the rock. The mineral is not confined to the prevailing platy sandstone and shale but occurs in the dolomite, intraformational conglomerate, and cross-bedded sandstone described below. An interesting feature of its occurrence is its association with deposits that were obviously laid down in shallow water.

Interbedded with the platy sandstone and shale are two types of rock which, although they form only a subordinate part of the Bright Angel shale, are particularly characteristic of the formation.

One of these rocks is a compact crystalline limestone whose color is deep snuff-brown on weathered surfaces and pale tan on freshly broken surfaces. Beds of this limestone are very resistant to erosion and make cliffs. In the region about Bass Canyon two beds vertically 35 feet apart appear in the Bright Angel shale at a horizon about 125 feet above its base and make two conspicuous brown cliffs in the slope above the Tonto platform. Each cliff is about 12 feet high. The beds of snuff-brown limestone, which determine the cliffs, range in thickness from a few inches to 8 feet and are associated with beds of green, magenta, and brown cross-bedded sandstone. The cliffs are sharply defined and are wonderfully persistent. (See Pl. XXI, *B*.) Wherever possible the Tonto trail in this part of the canyon follows the narrow ledge at the top of one or the other of these cliffs, because the ledges afford much smoother going than the dissected and débris-covered slopes of the Tonto platform below. Other beds of snuff-brown limestone appear in the Bright Angel shale between the twin cliffs just described and the base of the Muav limestone, but at Bass Canyon they are thin and do not make conspicuous cliffs. Most of them are associated with beds of greenish and magenta cross-bedded sandstone.

The snuff-brown limestone effervesces weakly with acid. Some beds contain no visible impurities, but others contain scattered grains of glauconite and tiny rounded grains of quartz and exhibit cross-bedding. Many beds contain broken shells of brachiopods. In places the limestone passes laterally into an intraformational conglomerate composed chiefly of rounded, flattened fragments of limestone but containing glauconite, quartz sand, and broken shells.

The following analysis of a specimen of the snuff-brown limestone forming the lower of the twin cliffs at Bass Canyon (see p. 35) probably represents approximately the composition of the purer limestone. The bed from which the specimen was taken contains no visible glauconite or quartz and appears to consist entirely of coarsely crystalline limestone.

Partial chemical analysis of snuff-colored limestone from Bright Angel shale.

[Alfred A. Chambers, analyst.]

Insoluble	2.66
$(Al, Fe)_2O_3$	5.44
CaO	29.54
MgO	18.26

From this analysis it appears that the rock is an impure dolomite. The presence of quartz grains in beds closely associated with the one analyzed suggests that the insoluble impurities are largely quartz sand, and the fact that the rock weathers brown suggests that the other impurities are largely iron. Inasmuch as the snuff-colored limestones effervesce weakly with acid and differ from one another chiefly in the amount of impurities that they contain I have called them all dolomites in this report.

Another characteristic rock in the Bright Angel shale is dark-green or magenta cross-bedded sandstone. Most of this sandstone forms rather massive beds, which range in thickness from a few inches to several feet. The component grains are rather coarse and in most beds are loosely cemented, so that the rock crumbles easily. Some beds, however, form weak cliffs. The chief constituent of the sandstone is quartz, but many beds contain glauconite and many contain a large amount of ferritic sandy mud and more or less hematite. Broken shells of brachiopods are abundant in some beds. These green and magenta sandstones are readily distinguishable from the prevailing platy sandstone by their deep colors, cross-bedding, absence of thin lamination, and relatively coarse texture. The colors of some beds are very striking, green shading into deep bottle-green and magenta into deep purplish brown. In places these colors are mingled in blotches in the same bed, producing a curious mottled effect. The greenish beds owe their color largely to glauconite, and the magenta beds owe theirs to ferritic material. Some beds associated with snuff-colored dolomite weather brown.

At Bass Canyon the thickness of the Bright Angel shale is 391 feet and I have divided it into two members—subdivision A, at the top, 58 feet thick, and subdivision B, below, 333 feet thick. Both subdivisions consist essentially of thin-bedded greenish and buff micaceous shale and sandstone, with which snuff-brown dolomite and greenish and magenta sandstone of the types just described are interbedded at irregular intervals. The character and succession of the beds are recorded in the columnar section (pp. 34–35). In general composition subdivision A differs from B only in that it contains, near the base, a few beds of mottled limestone similar to those which constitute subdivision D of the overlying Muav limestone. In a former report[11] I included subdivision A in the Muav limestone, placing the base of the Muav at the lowest point where mottled limestone appears in the Tonto group, but in the present report I have included subdivision A in the Bright Angel shale, which as here defined includes all strata between the white cross-bedded sandstone at the top of the Tapeats and the cliff-making gray and buff mottled limestone that constitutes subdivision D of the Muav. This definition is in accord with Walcott's observations at Kanab Creek. Wal-

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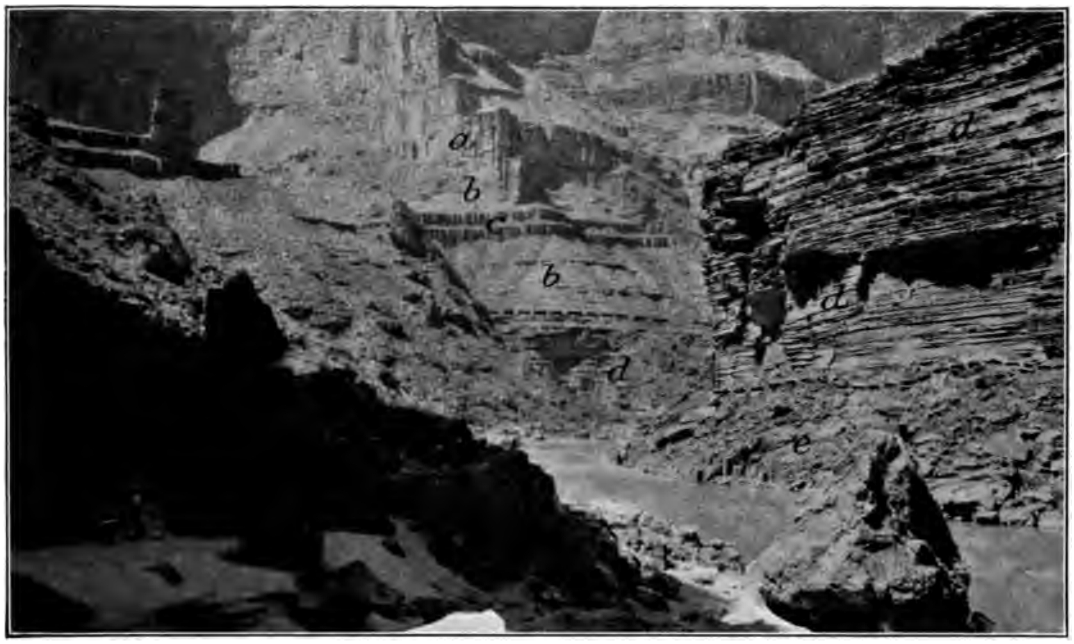
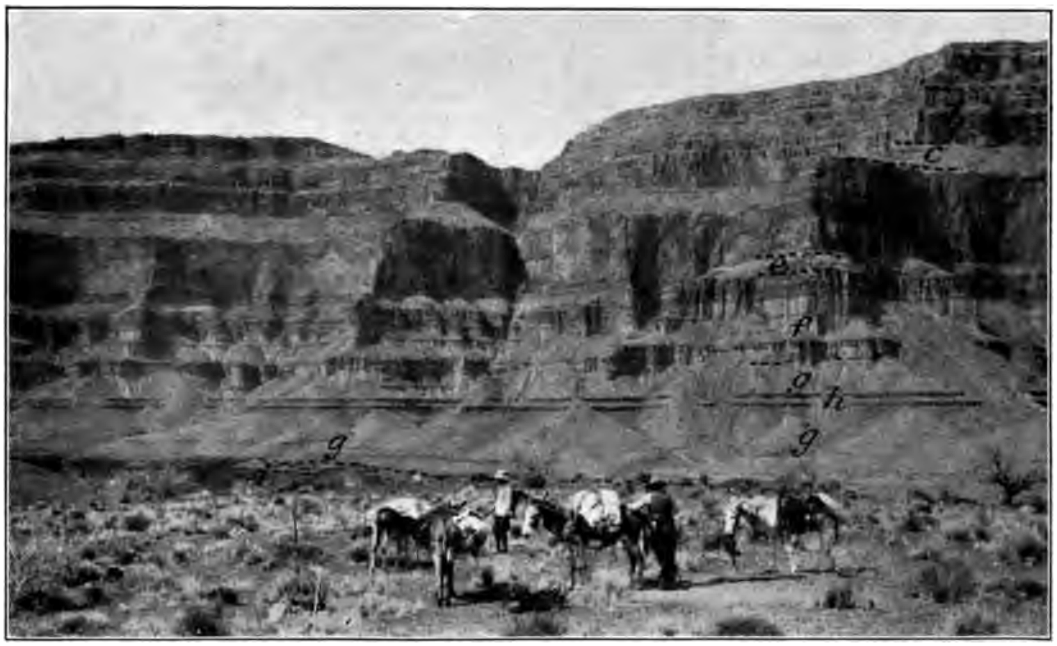
[11] Noble, L. F., op. cit., p. 65.



A. TYPICAL EXPOSURE OF TAPEATS SANDSTONE ON COLORADO RIVER OPPOSITE MOUTH OF ELVES CHASM, SHINUMO QUADRANGLE, ARIZ.

a, Muav limestone; *b*, Bright Angel shale; *c*, twin cliffs of snuff-colored dolomite of Bright Angel shale; *d*, Tapeats sandstone; *e*, Vishnu schist.



B. TYPICAL EXPOSURE OF BRIGHT ANGEL SHALE, MUAV LIMESTONE, TEMPLE BUTTE LIMESTONE, REDWALL LIMESTONE, AND SUPAI FORMATION IN NORTH WALL OF GRAND CANYON OPPOSITE GARNET CANYON, SHINUMO QUADRANGLE, ARIZ.

a, *b*, *c*, Supai formation, subdivisions A, B, C; *d*, Redwall limestone; *e*, Temple Butte limestone; *f*, Muav limestone; *g*, Bright Angel shale; *h*, twin cliffs of snuff-colored dolomite in Bright Angel shale; *i*, Tapeats sandstone.

cott's section at Kanab Creek (see Pl. XX) shows 100 feet of greenish micaceous shale and sandstone (d) beneath beds of mottled limestone (c) that are evidently equivalent to subdivision D of the Muav limestone of my Bass Canyon section. He states [12] that a mile or two east of Kanab Creek, where more of the greenish micaceous shale and sandstone (d) is exposed, the shale and sandstone pass downward into mottled gray limestone, calcareous and micaceous shale, and dark indurated sandstone. Probably this mottled gray limestone is equivalent to the mottled limestone that appears in thin beds at the base of subdivision A of the Bright Angel shale in my Bass Canyon section, so that subdivision d of Walcott's section at Kanab Creek is roughly equivalent to my subdivision A at Bass Canyon. Walcott states [13]: "I find on my locality label 75 that the thin-bedded sandstone and shale (d) at Kanab Creek is placed in the Bright Angel shale and the overlying mottled limestone (c) in the Muav limestone."

The columnar sections of the Tonto group shown on Plate XX trace the lithology of the Bright Angel shale through the greater part of the Kaibab division. They show that although the formation exhibits little change in general composition from place to place the interbedded layers of green and magenta sandstone and snuff-colored dolomite increase in number and become thinner and more widely distributed through the prevailing platy sandstone and shale toward the southeast. This change is shown clearly in the profiles of the different sections. Thus, at Garnet and Bass canyons the formation contains only two prominent sets of beds of green and magenta sandstone and snuff-brown dolomite, so that only two cliffs break the long slope formed by the platy beds. But southeast of Bass Canyon, at Slate, Hermit, and Pipe creeks, two other sets of beds of sandstone and dolomite have appeared above the lower pair, so that the slope is broken by four cliffs instead of two. These four cliffs are strongly defined at Slate Creek, fairly well defined at Hermit Creek, and poorly defined at Pipe Creek because the beds become thinner toward the southeast. Southeast of Pipe Creek, at Cottonwood Creek, these beds are so widely distributed in the platy sandstone and shale and are all so thin that no bed or set of beds makes a prominent cliff. Here the whole formation presents a continuous slope. Three miles east of Cottonwood Creek, at "Congress Canyon" (Red Canyon), that part of Frech's section of the Tonto group [14] which represents the Bright Angel shale is similar in lithology to my section of the Bright Angel shale at Cottonwood Creek.

Southeast of Bass Canyon beds of green and magenta sandstone are more abundant in the Bright Angel shale than beds of snuff-colored dolomite. In the region between Slate and Pipe creeks these sandstones have attracted attention as a possible source of platinum and at one time were extensively prospected. No samples of the rock examined by the Survey have yielded platinum, but some of the rock when crushed and panned yields a small amount of magnetite. At Slate Creek some of these sandstones, near the base of the Bright Angel shale, contain considerable hematite and form thin beds that are conspicuous by their bright-red color. Between Bass Canyon and Garnet Canyon some ferritic beds at this horizon exhibit oolitic structure. (See p. 35.)

Probably the beds of snuff-brown dolomite and sandstone that make the twin cliffs at Bass and Garnet canyons are traceable far west of the area covered by the present report, because a section of the Bright Angel shale at the mouth of the Grand Canyon [15] shows a double cliff of snuff-colored sandstone that is said to be continuous throughout the Shivwits division, Gilbert having traced it from the Grand Wash to Diamond Creek.

Southeastward from Bass Canyon the thin beds of mottled limestone at the base of subdivision A gradually give way to calcareous sandy shale and finally disappear southeast of Hermit Creek.

Few hills of pre-Cambrian rock rise far into the Bright Angel shale, but one hill on the north side of Colorado River about 3 miles east of Bass Canyon rises nearly to the top of subdivision B. So far as known, this is the highest hill of pre-Cambrian rock in the Grand Canyon.

Thickness.—The thickness of the Bright Angel shale decreases gradually from northwest to southeast. Thus the formation is 402 feet thick at Garnet Canyon, 391 feet at Bass Canyon, 392 feet at Slate Creek, 344 feet at Hermit Creek, 325 feet at Pipe Creek, and 334 feet (estimated) at Cottonwood Creek. At Nunkoweap Valley, 15 miles north of Cottonwood Creek, it is 325 feet thick. The beds equivalent to subdivision A of the Bass Canyon section decrease from 60 feet at Garnet Canyon to 42 feet at Pipe Creek, and the beds equivalent to subdivision B decrease from 342 feet at Garnet Canyon to 283 feet at Pipe Creek. At Cottonwood Creek the two subdivisions can not be separated with certainty.

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[12] Walcott, C. D., unpublished notes.

[13] Personal communication.

[14] Frech, F., Cong. géol. internat., 5e sess., Compte rendu, p. 479.

[15] U. S. Geog. and Geol. Surveys W. 100th Mer. Rept., vol. 3, p. 199, figs. 86, 87, 1875.

Fossils.—Fossils are abundant at several horizons in subdivision B of the Bright Angel shale. The following species listed in my report on the geology of the Shinumo quadrangle[16] were collected by Walcott or by me at several horizons in subdivision B in the region about Bass Canyon and Shinumo Creek:

Lingulepis spatulus.
Lingulella acutangula.
Lingulella lineolata.
Lingulella perattenuata.
Obolus (Westonia) themis.
Indiana faba.

At 25 feet above the base of subdivision B in Serpentine Canyon I have collected and Edwin Kirk has identified *Micromitra* (*Paterina*) *superba* and *Lingulella lineolata*, and at 165 feet above the base of subdivision B near Hermit Creek *Obolus* (*Westonia*) *chuarensis* and *Micromitra* (*Iphidella*) *pannula*.

At 100 to 120 feet above the base of subdivision B near the Bright Angel (Cameron) trail Walcott[17] has collected the following species:

Obolus (Westonia) chuarensis.
Eocystites? undet. sp.
Hyolithes.
Alokistocare althea.
Dolichometopus productus.
Dolichometopus tontoensis.

The age of this fauna is stated by Walcott to be Middle Cambrian.

In 1915 Schuchert studied the Bright Angel shale at Hermit Creek and collected fossils at several horizons. He states[18]:

> When the sandy muds were forming, seaweeds (*Palaeophycus*) were common, along with a great abundance of burrowing annelids. Trailings and fucoidal casts are nearly always to be seen, and also the vertical burrowings of worms like *Arenicolites*. * * * In spite of the fact that almost no good fossils are to be had in the Bright Angel formation, yet the physical phenomena show that the epeiric sea of this time must have been rich in life. This is proved by the abundance of fucoidal casts, trailings, and annelid burrows. Further, in some of the sandstones obolid fragments teem, and at times their shells make up one-third of a stratum. When the obolid shells are prevalent, glauconite is also common, and the formation of this mineral is probably conditioned by the decomposition of the organic remains. On the other hand, there are entire beds of glauconite up to a few inches thick that are almost devoid of fossils. When glauconite is very abundant, there are also apt to be thin beds and even zones a few feet thick of low-grade iron ore.
>
> *Palaeophycus* casts are very common and well preserved at 15 feet above the Tapeats sandstone, and 150 feet higher is a glauconitic sandstone replete with the brachiopods *Micromitra* (*Iphidella*) *pannula* (White) and *Obolus* (*Westonia*) *chuarensis*. Ten feet higher occur abundantly in thin-bedded sandstones *Obolus zetus* and rarely *Obolus* (*Westonia*) *themis* and *Lingulella acutangula*.
>
> The most prominent horizon for fossils, consisting almost entirely of obolids, is the one just mentioned, which occurs from 150 to 170 feet above the base of the Bright Angel formation and is at the same time a general level for thin-bedded sandstones.

It is evident that the age of at least the lower 170 feet of subdivision B of the Bright Angel shale is Middle Cambrian, as shown by fossils. I have found no determinable fossils in the upper part of the subdivision but have noted in a bed near the top small fragments of obolid shells similar to those that occur in the lower 170 feet. I have found no fossils in subdivision A at Bass Canyon, nor in beds that occupy the equivalent horizon at localities where I measured the other Tonto sections. But inasmuch as subdivision A differs in general lithologic character from subdivision B only in that it contains a few layers of mottled limestone, which gradually disappear east of Bass Canyon, and is evidently equivalent to a set of beds at Kanab Creek in which Walcott has found Middle Cambrian fossils and which he includes in the Bright Angel shale (see p. 41), I believe the entire Bright Angel shale as defined in this report is Middle Cambrian.

MUAV LIMESTONE.

Character.—At Bass Canyon the Muav limestone consists chiefly of impure limestone and calcareous sandstone but includes much platy sandstone and shale that do not differ from those which occur throughout the Bright Angel shale. Platy or shaly lamination is a prominent feature except at the top of the formation, but unlike the Bright Angel shale the Muav, as a whole, is fairly resistant to erosion and makes cliffs or steep slopes. The prevailing rock is a peculiar gray and buff mottled limestone, which occurs in countless beds averaging less than an inch thick. The lower two-thirds of the formation consists largely of this mottled limestone and partly of platy sandstone and shale; the upper third consists of calcareous sandstone overlain by massive magnesian limestone.

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[16] Noble, L. F., op. cit., p. 64.

[17] Walcott, C. D., Cambrian geology and paleontology: Smithsonian Misc. Coll., vol. 64, No. 5, p. 374, 1916.

[18] Schuchert, Charles, op. cit., p. 367.

Subdivisions.—At Bass Canyon four subdivisions with persistent features can be differentiated, although the boundaries between them are not sharp. The massive magnesian limestone at the top of the Muav constitutes subdivision A, 63 feet thick, and forms a strong cliff. The underlying calcareous sandstone constitutes subdivision B, 72 feet. This sandstone, massive at the top but thin-bedded at the base, makes a set of weak cliffs that in most places unite with the cliff formed by the overlying limestone. Beneath subdivision B is 241 feet of thin-bedded mottled limestone containing many interbedded layers of platy sandstone and shale. These alternating beds constitute subdivision C and form a steep slope. Beneath them is a cliff-making bed of relatively pure mottled limestone 97 feet thick, which constitutes subdivision D, at the base of the Muav.

In appearance the mottled limestone of the Muav is unlike any other rock in the Paleozoic section. Characteristically it is a hard thin-bedded impure limestone, whose outcrops when seen from a distance resemble outcrops of shale. The beds range in thickness from less than an eighth of an inch to several inches but commonly do not exceed half an inch. The purer limestone is gray, but most of the rock contains a considerable amount of buff material which was originally a fine-grained micaceous sandy mud. Some of this material forms shaly partings between the beds of limestone, and some of it is mixed with the limestone, so that in most beds the gray and buff colors are mingled. Many limestone beds are intraformational conglomerates composed of small flattened rounded pebbles of mottled limestone embedded in a matrix which in some places consists of crystalline limestone and in others of buff calcareous material. Nearly every bed of limestone or conglomerate exhibits numerous coralloid or fucoidal markings. These markings, which Newberry and other early observers ascribed to branching corals but which Schuchert and Walcott have shown to be largely the work of worms, are one of the distinctive features of the mottled limestone. Schuchert[19] states:

> Where the calcareous materials become more dominant the beds are completely riddled with vertical and anastomosing worm burrows. These are usually filled with a very fine sand, and it is this feature that gives so much of the Muav its mottled appearance and that led Gilbert many years ago to call the formation in the western part of the Grand Canyon the "mottled limestone." Throughout the middle third of the Muav many of the shaly limestones are intraformational conglomerates with the pebbles small, flat, and more or less rounded on the edges. It is an interesting shallow-water, near-shore marine deposit. This is shown in the great abundance of annelid burrows, in the intraformational conglomerates, and in the variable nature of the calcareous deposits. * * * The writer has not seen a Paleozoic marine deposit more bored into and consumed by mud eaters than this one, and these burrows are most prevalent in the calcareous zones. Worm castings are often well preserved in the thin-bedded shale zones and occur as little confused heaps or in circular sausage-like strings.

Most beds of the mottled limestone effervesce freely with acid. An analysis of a typical specimen from a bed that exhibits the usual mixture of gray limestone and buff sandy material is given below.

Partial chemical analysis of mottled limestone from Muav limestone.

[Albert A. Chambers, analyst.]

Insoluble	23.46
$(Al, Fe)_2O_3$	2.54
CaO	48.25
MgO	Trace.

This analysis shows that the limestone is not magnesian and indicates that the sandy impurities constitute about a quarter of the rock.

Subdivision D, at the base of the Muav, consists almost wholly of the thin-bedded mottled limestone just described and contains very little limestone of the intraformational-conglomerate type. In the basal 10 feet of the subdivision thin layers of fine-grained platy sandstone are interbedded with the limestone. These alternating beds define the lower limit of the Muav limestone, and their separation from the underlying greenish shale and platy sandstone of the Bright Angel shale is distinct at Bass Canyon, although they represent a transition in lithology rather than an abrupt change. Owing to the hardness of the mottled limestone subdivision D forms a strong cliff, a feature which at once distinguishes it from the overlying subdivision C and from the underlying Bright Angel shale, which forms slopes. Just beneath the cliff are the soft underlying greenish shale and sandstone, which persist over a considerable area east and west of Bass Canyon and etch out everywhere, leaving a small alcove overhung by the cliff. The alcove will guide the observer to the contact between the Bright Angel shale and the Muav limestone.

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[19] Schuchert, Charles, op. cit., pp. 368, 369.

Subdivision C consists chiefly of thin-bedded mottled limestone but unlike subdivision D contains many thin interbedded layers of sandstone and shale. The character and succession of the strata, which are variable in composition and occur in countless alternations, are shown in the detailed section on pages 33–34. Some parts of the subdivision contain as much sandstone and shale as mottled limestone, but other parts contain considerably more mottled limestone than any other rock, and large parts consist almost entirely of mottled limestone. The mottled limestone in subdivision C, unlike that in the underlying subdivision, is chiefly of the intraformational-conglomerate type. In general the beds contain more worm markings than those of subdivision D and vary more in thickness and composition. Some beds attain a thickness of a foot or more, and many are from 4 to 6 inches thick, although most are less than 1 inch. The thicker beds of intraformational conglomerate are lenticular, exhibiting considerable variation within horizontal distances of a few hundred feet. Glauconite occurs sparingly in some strata. Most of the interbedded sandstone and shale resemble those which prevail in the Bright Angel shale. The sandstone is fine grained, quartzose, and micaceous and occurs in thin platy layers; the shale is greenish, soft, micaceous, and sandy. Some of the sandstone, however, is calcareous and resembles that which occurs in the overlying subdivision B. A prominent bed of hard brownish-buff cross-bedded calcareous sandstone 8 feet thick appears at a horizon 142 feet above the base of subdivision C and makes a small conspicuous and persistent brown cliff that is traceable over many miles in the region about Bass Canyon. Other beds of calcareous sandstone are interbedded with intraformational conglomerate and platy quartzose sandstone at the top of the subdivision. Some of these upper beds exhibit purplish spots and mottlings similar to those which appear in the rocks of subdivision B, and some of the intraformational conglomerates are purplish.

Subdivision B consists chiefly of fine-grained calcareous sandstone but includes beds of platy quartzose sandstone, sandy micaceous shale, crystalline limestone, dolomite, and intraformational conglomerate. The prevailing color of the strata is pale buff, but pinkish, purplish, and greenish hues occur. Many beds contain pinkish or purplish blotches and mottlings. The upper portion of the subdivision is relatively thick bedded, many beds attaining a thickness of 2 feet or more. The lower portion contains some beds as much as 1 foot thick but in general is thin bedded. Toward the base the lamination becomes shaly and many layers are as thin as cardboard. Most of the subdivision forms a cliff or a steep ledgy slope broken by cliffs.

The typical calcareous sandstone is hard, compact, and fine grained, effervesces with acid, and is easily scratched with a knife. Weathered surfaces feel gritty and display indistinct cross-bedding, although freshly broken surfaces may exhibit no cross-bedded structure. Some beds are crystalline and consist entirely of calcareous material. Others contain more or less fine quartzose and micaceous sand. It is difficult to decide whether to classify some beds as limestone or as calcareous sandstone, but the cross-bedded structure indicates that the component material, whatever its composition, is of clastic origin.

The upper half of the subdivision is composed largely of the calcareous sandstone just described. Here and there a bed of pinkish or purplish crystalline limestone is interbedded with the calcareous sandstone. Beds of fine quartzose sandstone, sandy shale, and intraformational conglomerate appear at several horizons, and near the top of the subdivision there is a bed or two of dolomite similar to that in the overlying subdivision A. The lower half of the subdivision is composed partly of calcareous sandstone and partly of platy quartzose micaceous sandstone, sandy micaceous shale, and intraformational conglomerate. Worm markings are abundant, and some beds exhibit sun cracks and ripple marks. Scattered grains of glauconite occur in some beds. Most beds in the lower part of the subdivision do not effervesce with acid.

Although intraformational conglomerate may appear at any horizon in subdivision B it does not form thick sets of beds and is not abundant in the subdivision as a whole. Most of it differs in composition from the conglomerate in the underlying subdivision in that, although composed chiefly of small flattened rounded pebbles, it is not essentially a limestone. Most of the pebbles are fine-grained sandstone, and the matrix is fine sand.

Subdivision A, at the top of the Muav, consists of hard buff limestone which forms massive beds from 2 to 10 feet thick. Thin partings of sandy shale separate some beds. The limestone is entirely crystalline and exhibits no bedded structure on freshly broken surfaces, but weathered surfaces show faint traces of cross-bedding. Most of the rock contains small cavities, some of which are filled with crystalline material. Some beds exhibit purplish blotches and mottlings. Most beds do not effervesce with acid, although some effervesce feebly. The following analysis shows the composition of a typical specimen of the limestone from a bed 15 feet above the base of the subdivision in Bass Canyon.

Partial chemical analysis of limestone from subdivision A, Muav limestone.

[Alfred A. Chambers, analyst.]

Insoluble	1.52
$(Fe, Al)_2O_3$	.80
CaO	30.10
MgO	20.78

From this analysis it appears that the rock is a magnesian limestone that differs little in composition from typical dolomite. The small amount of insoluble material which the rock contains suggests that if, as the indistinct cross-bedding indicates, the rock was composed originally of detrital sand, the sand was calcareous, not siliceous.

These massive dolomites of subdivision A are the most resistant strata in the Tonto group and in consequence of their hardness weather everywhere into strong cliffs. In appearance they are wholly unlike the thin-bedded strata of the Bright Angel shale and lower Muav, resembling rather beds at the base of the great cliff formed by the Redwall limestone. However, they are separated from the Redwall cliff in Bass Canyon by 75 feet of thinly laminated beds that form a slope, so that the observer will experience no difficulty in distinguishing them from the Redwall strata. The upper limit of subdivision A is an unconformity of erosion, which is described on pages 49–51.

Thickness and correlation.—The columnar sections in the Kaibab division of the Grand Canyon (see Pl. XX) in connection with Walcott's section at Kanab Creek (see Pl. XIX) trace the lithology of the Muav limestone through a distance of 50 miles southeastward. These sections show that the formation thins steadily from northwest to southeast. The thickness at Kanab Creek is 685 feet; at Garnet Canyon, 504 feet; at Bass Canyon, 473 feet; at Slate Creek, 429 feet; at Hermit Creek, 419 feet; at Pipe Creek, 383 feet; and at Cottonwood Creek (estimated), 238 feet. At Nunkoweap Valley the thickness is 425 feet, but this locality is 15 miles north of Cottonwood Creek. Thus the formation loses about two-thirds of its thickness in the 50 miles between Kanab Creek and Cottonwood Creek. The thinning is due primarily to decrease in deposition, not to erosion, although at some places—for example, at Cottonwood Creek—more beds have been removed below the erosional unconformity at the top of the Muav than at others.

The chief lithologic units into which the formation is divisible at Bass Canyon are recognizable in all the other sections, although it is difficult to trace from one locality to another the exact boundaries that limit the subdivisions, because the strata undergo gradual changes in composition from place to place and the subdivisions grade into one another vertically. Broadly the lower two-thirds of the formation everywhere is thin bedded and consists of mottled limestone and interbedded sandy material, whereas the upper third is comparatively thick bedded and consists of calcareous sandstone below and massive limestone above. Large parts of the formation, however, become increasingly sandy toward the southeast. At Kanab Creek the formation consists chiefly of limestone, whereas at Cottonwood Creek, 50 miles southeast of Kanab Creek, and at Nunkoweap Valley, 15 miles north of Cottonwood Creek, it consists chiefly of calcareo-arenaceous rocks.

Most of the lithologic change occurs in subdivisions C and D. (See Pl. XX.) Thus at Bass Canyon subdivision D, at the base of the Muav, is 97 feet thick and consists almost wholly of mottled limestone. Only 10 feet of limestone, at the base of the subdivision, contains interbedded layers of sandstone. At Slate Creek, southeast of Bass Canyon, the mottled limestone of subdivision D is 50 feet thick, and the basal 44 feet of the subdivision is made up of alternating beds that consist chiefly of sandstone and shale but include a few layers of mottled limestone. That these prevailingly sandy beds are actually a part of subdivision D as defined at Bass Canyon and are not equivalent to beds included in the Bright Angel shale at Bass Canyon is clear, because the conspicuous soft green shale that marks the upper limit of the Bright Angel shale at Bass Canyon (see p. 34) is traceable continuously from Bass Canyon to Slate Creek. At Hermit Creek the mottled limestone of subdivision D is 40 feet thick and the underlying sandy beds 42 feet; and at Pipe Creek, still farther southeast, the mottled limestone is 34 feet thick and the sandy beds 51 feet. At the last two localities the mottled limestone interbedded with the sandy beds is very impure, so that the beds do not differ conspicuously from the Bright Angel shale and are difficult to separate from it. At Cottonwood Creek, southeast of Pipe Creek, the mottled limestone at the top of subdivision D is only 25 feet thick and overlies beds of greenish sandstone which contain layers of impure mottled limestone in the upper 17 feet. Here I have placed the base of subdivision D at a point 37 feet below the 25-foot bed of mottled limestone. This horizon, as nearly as I could determine, is equivalent to that which marks the top of the Bright Angel shale at Bass Canyon, but the horizon is not actually traceable between Bass Canyon and Cottonwood Creek. Probably, however, my estimate of its position at Cottonwood Creek is correct within 25 feet.

West of Bass Canyon, at Garnet Canyon, the mottled limestone is 122 feet thick and occupies all of subdivision D. A few thin layers of sandy material are interbedded with the basal 6 feet of the limestone.

Thus subdivision D decreases in thickness and undergoes a gradual change in composition southeastward through the Kaibab division. It decreases from 122 feet at Garnet Canyon to 62 feet at Cottonwood Creek, 28 miles southeast of Garnet Canyon. At Garnet Canyon it consists almost entirely of mottled limestone; at Cottonwood Creek it contains only a third as much mottled limestone as sandstone and shale, the limestone measuring only 25 feet. The increase of sandy material in the lower part of the subdivision makes its separation from the Bright Angel shale increasingly difficult southeast of Bass Canyon.

Subdivision C, like subdivision D, decreases in thickness southeastward. At the type locality, at Bass Canyon, it is 241 feet thick. Southeast of Bass Canyon equivalent beds are 225 feet thick at Slate Creek, 215 feet at Hermit Creek, 185 feet at Pipe Creek, and 176 feet at Cottonwood Creek. These correlations are necessarily approximate, because subdivision C is nowhere separated from the overlying and underlying subdivisions by sharp lithologic changes, but in general the limits of the beds correlated with subdivision C are believed to be correctly placed within 25 feet. At all localities the subdivision is prevailingly calcareous but variable in composition, thin beds of mottled limestone, intraformational conglomerate, sandstone, and shale succeeding one another in countless alternation, yet it contains much more limestone in proportion to sandy material at Garnet Canyon than at Cottonwood Creek and thus, like subdivision D, becomes increasingly sandy toward the southeast. Glauconite, which occurs sparingly in the subdivision at Garnet and Bass canyons, becomes increasingly abundant southeast of Bass Canyon.

Subdivisions C and D together constitute that part of the Muav limestone in which thin-bedded mottled limestone is the prevailing rock and occupy the lower two-thirds of the formation. I have separated them at Bass Canyon, (1) because at that locality subdivision D consists essentially of mottled limestone, whereas subdivision C includes many interbedded layers of sandstone and shale; (2) because practically no limestone in subdivision D is of the intraformational-conglomerate type, whereas most of the limestone in subdivision C is intraformational conglomerate; and (3) because the two subdivisions differ in topographic expression, D forming a cliff and C forming a slope. Walcott in his sections at

Kanab Creek and Nunkoweap Valley (see Pls. XIX and XX) does not subdivide this part of the Muav in which mottled limestone is the prevailing rock.

The mottled limestone at Kanab Creek is described by Walcott[20] as follows:

> The limestone is hard and brittle, breaking into angular fragments. Arenaceous shaly partings occur at various horizons, and there is considerable arenaceous detrital matter mixed with the limestone. At the base a massive bed 70 feet in thickness occurs, which is followed by several hundred feet of thin-bedded limestones. Many layers are gray limestone full of small flattened fragments [intraformational conglomerate?]. Toward the summit the upper 85 feet is essentially a repetition of the 70 feet at the base. The entire mass has a thickness of 450 feet. The coralline mottling, as it has been called by authors, extends from base to summit. That a portion of the mottling is produced by the former presence of branching corals may be true, but that such is usually the case is questioned. A study of the various forms of ramifying annelid trails and borings in the shales beneath prepares us to look for the origin of the mottling in that direction. On the surface of the intercalated arenaceous shales and also of the shaly sandstone layers these trails are seen in abundance. They may be traced into the limestone from the surface. Where the matrix is arenaceous they are frequently calcareous, and in the calcareous layers they are often silicified. Usually of a purplish color, they may be gray or buff according to the material by which they have been replaced. * * * I should assign to annelids by far the greater share in the origin of the mottling of the limestone.

The 450-foot mottled-limestone member just described constitutes subdivision c of Walcott's section at Kanab Creek and is undoubtedly roughly equivalent to subdivisions C and D of my Bass Canyon section. At Nunkoweap Valley it constitutes subdivision 3 of Walcott's section, is 340 feet thick, and is a series of mottled and variegated calcareo-arenaceous rocks. Thus it decreases from 450 feet at Kanab Creek to 338 feet (the aggregate thickness of subdivisions C and D) at Bass Canyon, 30 miles southeast of Kanab Creek. Between Bass Canyon and Nunkoweap Valley, 30 miles to the northeast, the thickness changes very little, but between Bass Canyon and Pipe Creek, 18 miles to the southeast, it decreases from 338 to 270 feet, and at Cottonwood Creek, southeast of Pipe Creek, it appears to be less than it is at Pipe Creek. Walcott's descriptions indicate that the member is much less sandy at Kanab Creek than at Nunkoweap Valley and somewhat less sandy at Kanab Creek than at Bass Canyon. It is therefore evident that the member as a whole becomes increasingly sandy southeastward from Kanab Creek.

Subdivisions A and B, which constitute the upper third of the Muav at Bass Canyon, are represented by equivalent strata in all the sections shown on Plates XIX and XX, except in the section at Cottonwood Creek, where they have been removed by erosion.

The relatively thick-bedded calcareous sandstone in the upper part of subdivision B of my Bass Canyon section is evidently equivalent to the gray and buff calciferous sandrock, 50 feet thick, which constitutes subdivision B of Walcott's section at Kanab Creek, and to the yellowish sandstone, 25 feet thick, which constitutes subdivision 2 of his section at Nunkoweap Valley. Probably subdivision B as defined by me includes a wider range of strata than the corresponding subdivision as defined by Walcott, and if so the thin-bedded sandstones of variable composition in the lower part of my subdivision B may be equivalent to beds of limestone at the top of Walcott's subdivision C at Kanab Creek and to beds of calcareo-arenaceous rocks at the top of his subdivision 3 at Nunkoweap Valley. Subdivision B as defined at Bass Canyon does not appear to undergo any significant lithologic change in the area between Garnet Canyon and Pipe Creek. The thick-bedded calcareous sandstone in the upper portion maintains a thickness of about 35 feet, whereas the subdivision as a whole varies irregularly in thickness, being 78 feet thick at Garnet Canyon, 72 feet at Bass Canyon, 95 feet at Slate Creek, 93 feet at Hermit Creek, and 87 feet at Pipe Creek. The fact that the boundary between subdivisions B and C is indefinite suggests that these variations may be only apparent, because in measuring some sections I may have included in subdivision B beds that are actually equivalent to beds in the underlying subdivision C of the Bass Canyon section.

Subdivision A as defined at Bass Canyon consists of massive buff crystalline limestone whose composition is approximately that of dolomite and which appears to be formed largely of calcareous or dolomitic sand. This subdivision is constant in lithologic character in all the sections between Garnet Canyon and Pipe Creek but exhibits many irregularities in thickness, owing to the fact that its upper surface is an unconformity of erosion. Its thickness is 70 feet at Garnet Canyon, 63 feet at Bass Canyon, 15 feet at Slate Creek, 29 feet at Hermit Creek, and 26 feet at Pipe Creek. In the region between Bass Canyon and Hermit Creek the beds of subdivision A have been entirely removed at many places and a large part of the underlying subdivision B has been removed at some places. These variations in thickness show the character and relief of the surface produced by erosion after the beds of subdivision A were deposited but afford no evidence concerning the original thickness of the beds.

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[20] Walcott, C. D., unpublished notes.

Subdivision A is apparently equivalent to the massive mottled limestone, 60 feet thick, which constitutes subdivision 1 of Walcott's section at Nunkoweap Valley and to the massive arenaceous and more or less mottled limestone, 185 feet thick, which constitutes subdivision a of his section at Kanab Creek. At Kanab Creek, at Nunkoweap Valley, and in the area between Garnet Canyon and Pipe Creek these limestones lie at the top of the Muav. Everywhere, therefore, they occupy the same stratigraphic position with regard to the underlying beds of calcareous sandstone of subdivision B. Moreover, if it is assumed that the sand in Walcott's limestones is calcareous, they do not appear to differ conspicuously from the equivalent beds in the area between Garnet Canyon and Pipe Creek. Some of the beds in this intermediate area exhibit purplish blotches and mottlings, and all of them, like Walcott's beds, are massive. Inasmuch as the top of subdivision A is eroded at Kanab Creek and at Nunkoweap Valley as well as in the intermediate area it is impossible anywhere to determine the original thickness of the subdivision and consequently of the Muav limestone.

Frech's section[21] at "Congress Canyon" (Red Canyon), 3 miles east of Cottonwood Creek, shows only 129 feet of strata at the summit of the Tonto group that can be confidently assigned to the Muav limestone. Probably he has included strata in the Redwall limestone which are actually equivalent to the Muav and Temple Butte limestones, because the thickness of 1,000 feet which he assigns to the Redwall at that locality is certainly too great by several hundred feet.

Fossils.—Fossils are scarce in the Muav limestone. At Kanab Creek, from the lower bed of mottled limestone in subdivision c of his section, Walcott[22] obtained the following species:

Hyolithes primordialis?
Lingulepis prima?
Acrotreta? sp.
Orthisina sp.
Ptychoparia sp.
Bathyurus? sp.

This bed of mottled limestone is probably roughly equivalent to my subdivision D of the Muav at Bass Canyon. (See pp. 43–44.)

From the upper bed of mottled limestone in subdivision c at Kanab Creek Walcott obtained the forms listed above and in addition a species of *Lingula*. This mottled limestone is probably equivalent to beds in the upper part of my subdivision C at Bass Canyon.

From beds in the upper part of the Muav limestone at Kanab Creek which are probably equivalent to my subdivision A at Bass Canyon Walcott obtained a species of *Trematis* and an imperfect specimen of *Discina*.

At Nunkoweap Valley the beds at the top of the Muav which are equivalent to my subdivision A at Bass Canyon are reported by Walcott to contain *Lingulepis* and *Ptychoparia*. (See columnar section at Nunkoweap Valley, Pl. XX.)

In the area covered by my sections between Garnet Canyon and Cottonwood Creek I have obtained fossils from the Muav limestone at only one locality. At Hermit Creek, from a bed of mottled limestone in subdivision C, 118 feet above the base of the subdivision, I collected

Finkelnburgia sp.
Syntrophia sp.
Anomocarella sp.
Pagodia? sp.
Ptychoparia? sp.

The locality is on the west slope of Cope Butte a few hundred feet north of the Hermit trail. The fossils were identified by Edwin Kirk, who states:

> The fauna as shown in the collection might be either Middle or Upper Cambrian. I think more extensive collections are needed definitely to prove its age. In this connection a faunal list given by Walcott[23] might be of interest. This fauna is cited from the Tonto at Kanab Creek and is given as Upper Cambrian.

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[21] Frech, F., op. cit., p. 479.

[22] Walcott, C. D., unpublished notes.

[23] Walcott, C. D., U. S. Geol. Survey Mon. 51, p. 214, locality 75, 1912.

At Hermit Creek, from a bed in subdivision C, 50 feet lower than that in which I found the fossils listed above, Schuchert[24] obtained pygidia of *Saukia* and of *Neolenus*. In discussing the fossils collected at Hermit Creek he states, "These fossils, and more especially the trilobites, show that the Muav is of Upper Cambrian age."

Regarding the age of the Muav limestone Walcott[25] states:

> As far as can be determined from the present collections I should include the Muav limestone in the Upper Cambrian; the Bright Angel shale and Tapeats sandstone in the Middle Cambrian. However, it is very desirable that larger collections be made from the Muav limestone.

Therefore I have assigned the Muav limestone to the Upper Cambrian in the present report, although I realize that further collections of fossils are necessary before its age can be fixed definitely. A careful search for fossils at the top of the formation may yield interesting results, for if the Muav is in fact Upper Cambrian it is conceivable that strata younger than Cambrian and older than Upper Devonian may be preserved in some places beneath the surface of erosion at the top of the formation.

UNCONFORMITY BETWEEN CAMBRIAN AND DEVONIAN SYSTEMS.

Walcott has shown that both at Kanab Creek[26] and in the region about Nunkoweap Valley,[27] 50 miles southeast of Kanab Creek, the upper limit of the Tonto group is an unconformity. The unconformity at Kanab Creek he describes as a strong line of erosion that in places exhibits vertical irregularities of 80 feet within horizontal distances of a few hundred feet. In studying the Tonto group between Garnet Canyon and Cottonwood Creek I have traced this unconformity through a distance of about 28 miles in the south wall of the Grand Canyon in the Kaibab division. (See Pl. XX.) Probably, therefore, it extends continuously from Kanab Creek to Nunkoweap Valley. Further study may show that it extends far west of Kanab Creek.

Inasmuch as the unconformity lies within horizontal strata it can not be detected by discordance of dip and is plainly recognizable only where the eroded surface exhibits strong relief. In places where the eroded surface is level or nearly level, as, for example, at Bass Canyon and at Cottonwood Creek, the unconformity is obscure. Even where the surface is moderately irregular, as in the region about the Hermit and Bright Angel trails, the visitor may at first experience considerable difficulty in recognizing the unconformity until he knows exactly where to look for it.

At present the Hermit and Bright Angel trails afford the visitor the easiest opportunity to examine the unconformity. If he will descend either of these trails to a point about a hundred feet below the base of the sheer cliff formed by the Redwall limestone, pick out the beds of massive cliff-making dolomite that constitute the topmost subdivision of the Muav limestone (see Pl. XX), and follow their upper surface, he will find broken-down areas in the top of the dolomite cliff, which at first sight may appear to be caused by masses of rock breaking off from the cliff but which close inspection will show to be hollows eroded in the dolomite and filled by overlying strata. As a rule the strata in the hollows exhibit pale purplish or pinkish tints, which contrast slightly with the prevailing buff or gray of the dolomite, although in many places their color is obscured by buff and gray stains washed over them from overlying beds. Moreover, they are softer than the dolomite and are irregularly bedded, so that they weather more easily than the dolomite and form slopes. Commonly, these slopes are wholly or partly covered with talus.

In the canyon of Garden Creek, through which the Bright Angel trail descends from the rim of the Grand Canyon at El Tovar, a hollow of the type just described is well exposed near the north end of the promontory that separates the canyon of Garden Creek from that of Pipe Creek. This hollow lies about half a mile east of Indian Garden and may be reached by leaving the trail near Indian Garden and climbing the long slope of Bright Angel shale and Muav limestone east of the Garden. Other hollows are exposed in the canyon of Garden Creek which the visitors will easily discover when he has learned where to look for them. The canyon of Pipe

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[24] Schuchert, Charles, op. cit., p. 369.

[25] Walcott, C. D., personal communication.

[26] Walcott, C. D., The Permian and other Paleozoic groups of the Kanab Valley, Ariz.: Am. Jour. Sci., 3d ser., vol. 20, pp. 221-225, 1880.

[27] Walcott, C. D., Pre-Carboniferous strata in the Grand Canyon of the Colorado, Ariz.: Am. Jour. Sci., 3d ser., vol. 26, p. 438, 1883.

Creek, east of Garden Creek, contains at least ten of them. Several are exposed in each of the canyons west of Garden Creek, between Garden Creek and Hermit Creek.

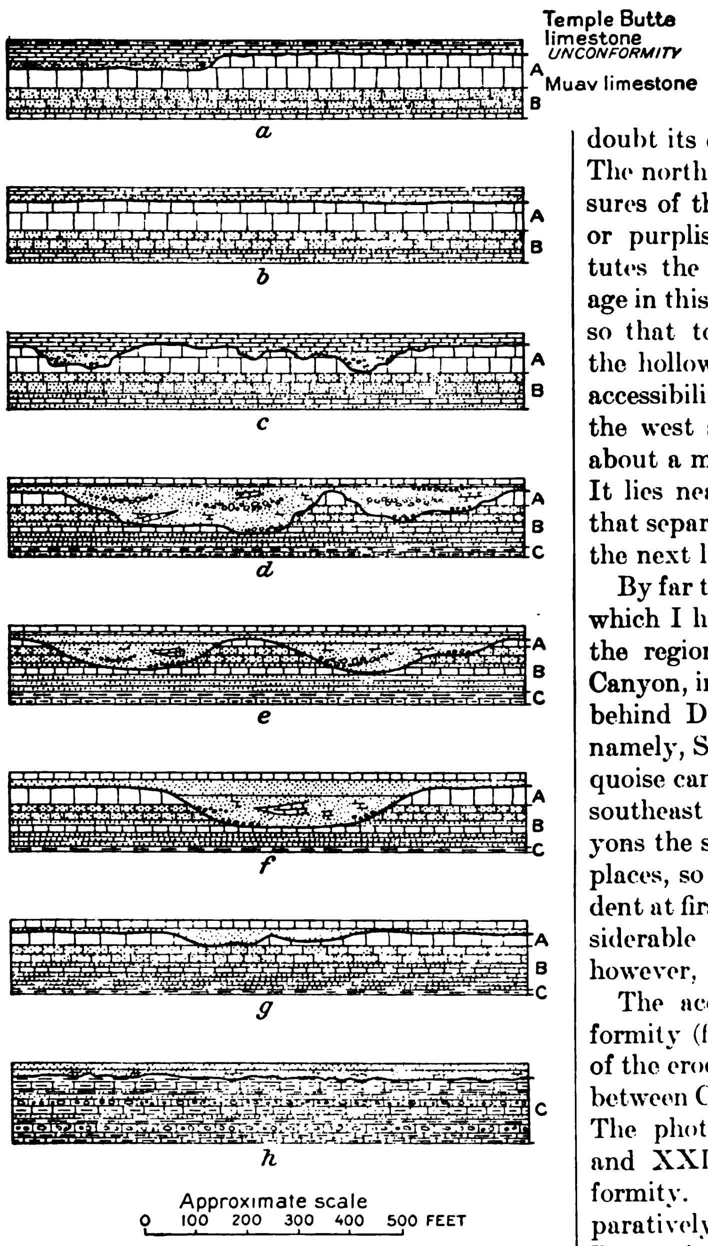
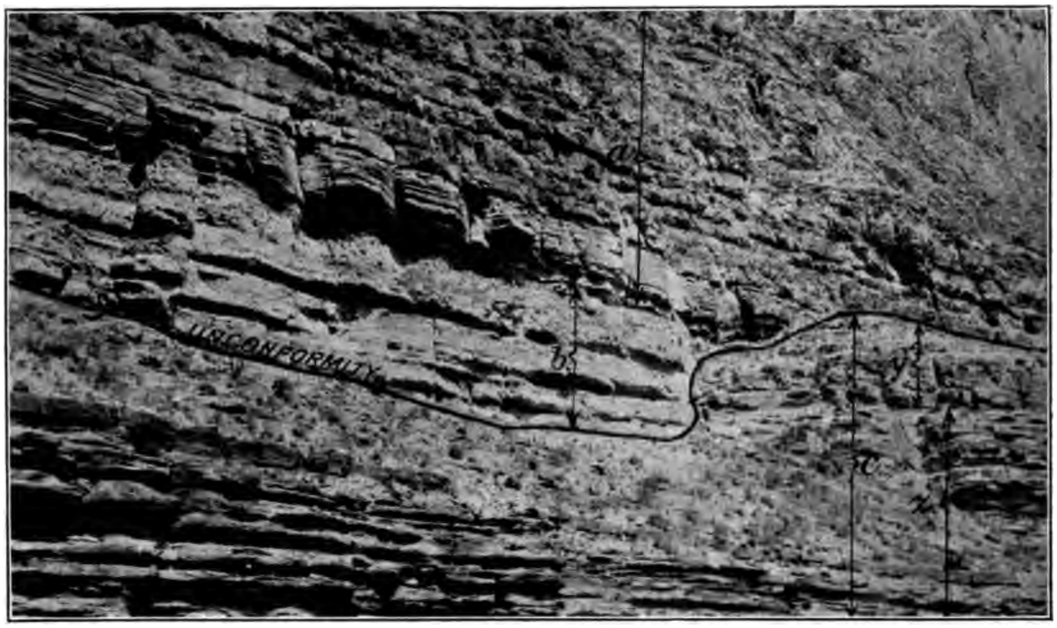


Figure 3.—Diagrammatic sketches showing general character of unconformity between Temple Butte limestone and Muav limestone at eight localities between Garnet Canyon and Cottonwood Creek, Grand Canyon, Ariz. *a*, Garnet Canyon; *b*, Bass Canyon; *c*, Ruby Canyon; *d*, Turquoise Canyon; *e*, Slate Creek; *f*, Hermit Creek; *g*, Pipe Creek; *h*, Cottonwood Creek.

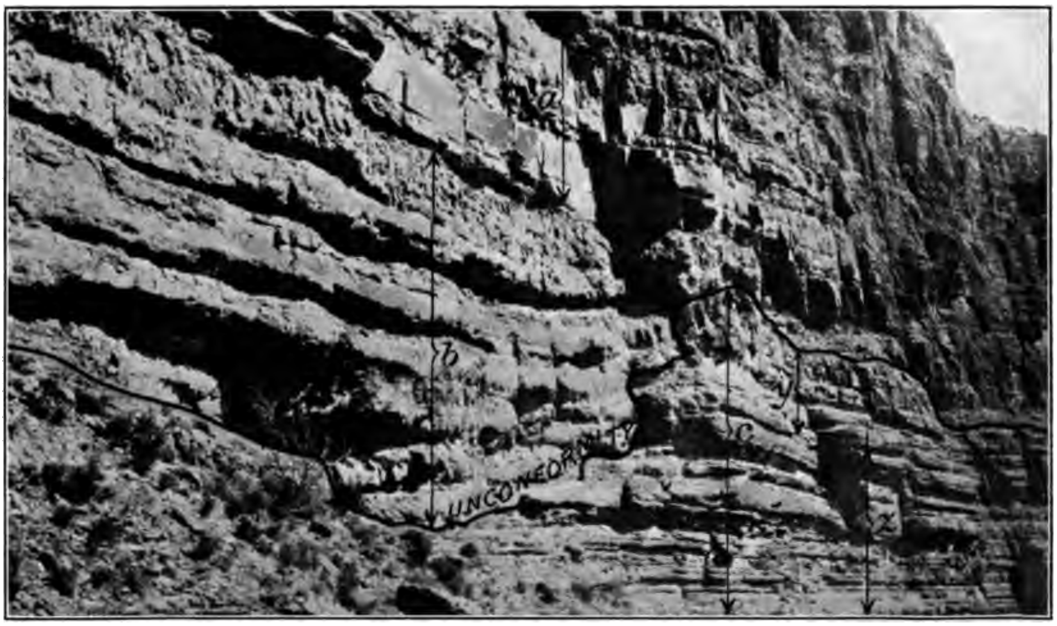
In the canyon of Hermit Creek a hollow nearly 80 feet deep lies in the northern slope of Cope Butte just east of and above the Hermit trail. To reach this hollow the visitor should leave the trail at the lower end of the tangent called "Long Drag" and climb eastward several hundred feet up the steep ledgy slope formed by subdivisions C and B of the Muav limestone, following a contact between bare rock on his left and talus on his right. The hollow is difficult to find, because all but the north end of it is concealed by talus, and the observer may doubt its existence until he actually reaches it. The north end of the hollow affords good exposures of the gnarly, irregularly bedded pinkish or purplish calcareous sandrock that constitutes the typical deposit of known Devonian age in this part of the Grand Canyon (see p. 51), so that to one interested in the stratigraphy the hollow is well worth a visit because of its accessibility. A similar hollow is exposed on the west side of the canyon of Hermit Creek about a mile west of the hollow just described. It lies near the north end of the promontory that separates the canyon of Hermit Creek from the next large canyon west of it.

By far the best exposures of the unconformity which I have seen in the Grand Canyon are in the region between Hermit Creek and Bass Canyon, in the long straight canyons that head behind Diana, Pollux, and Castor temples, namely, Slate Creek, Agate, Sapphire, and Turquoise canyons; also in Ruby Canyon, 2½ miles southeast of Bass Canyon. In all these canyons the surface of erosion is irregular in many places, so that the unconformity is plainly evident at first sight, even when viewed from a considerable distance. This interesting region, however, is not easily accessible to the tourist.

The accompanying sketches of the unconformity (fig. 3) show the topographic character of the eroded surface at eight different localities between Garnet Canyon and Cottonwood Creek. The photographs reproduced in Plates XXII and XXIII, *A*, show details of the unconformity. At Garnet Canyon the surface is comparatively even and exhibits no narrow hollows. Depressions are eroded in it, but they appear to be so broad and flat that the general aspect of the surface is mesa-like. At Bass Canyon, 3 miles from Garnet Canyon, the surface is practically level, and I have observed only one irregularity in it in a distance of several thousand feet. This irregularity is a steplike drop of about 25 feet from one mesa-like level to another. At Ruby Canyon, 2½ miles from Bass Canyon, the surface is very uneven. The



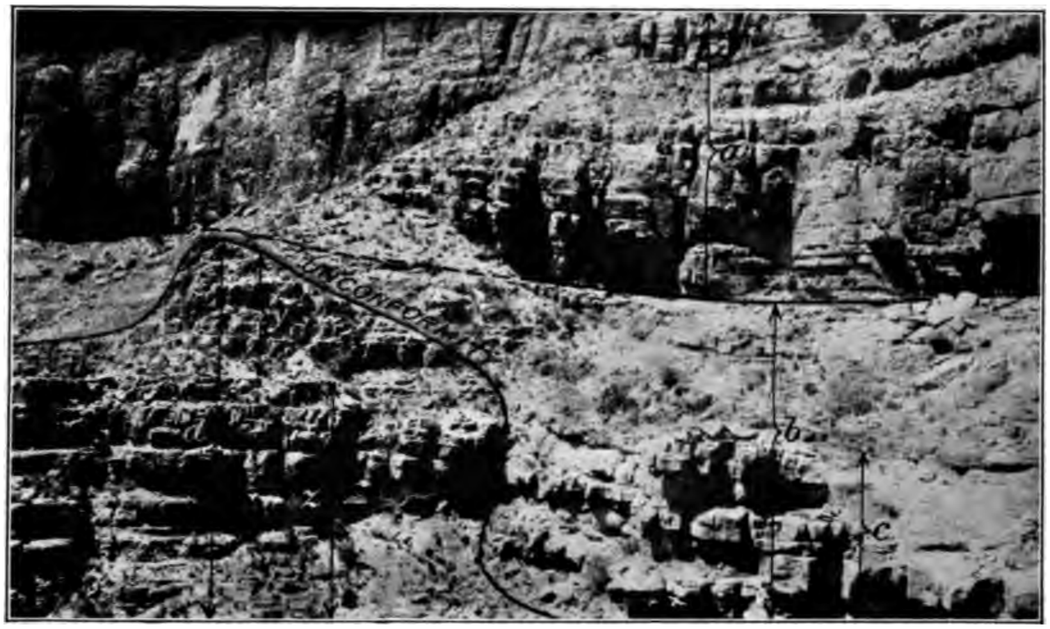
A.



B.

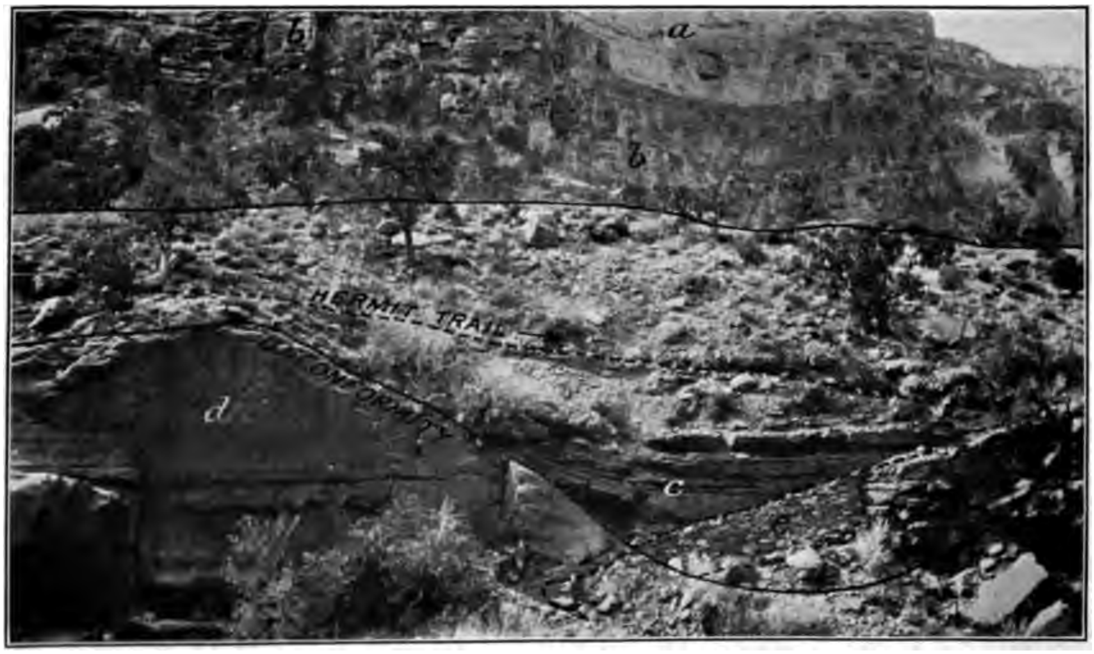
UNCONFORMITY BETWEEN TEMPLE BUTTE LIMESTONE AND MUAV LIMESTONE IN WEST WALL OF CANYON OF SLATE CREEK, SHINUMO QUADRANGLE, ARIZ.

a, Redwall limestone; *b*, Temple Butte limestone; *c*, Muav limestone; *y*, *z*, subdivisions A, B of Muav limestone. The human figure just at the right of the sharp bend in the unconformity in *A*, gives an idea of the scale of the photograph.



A. UNCONFORMITY BETWEEN TEMPLE BUTTE LIMESTONE AND MUAV LIMESTONE IN WEST WALL OF TURQUOISE CANYON, SHINUMO QUADRANGLE, ARIZ.

a, Redwall limestone; **b**, Temple Butte limestone; **c**, conglomerate; **d**, Muav limestone; **y**, **z**, subdivisions A, B of Muav limestone.



B. UNCONFORMITY BETWEEN HERMIT SHALE AND SUPAI FORMATION AT RED TOP, ON HERMIT TRAIL, BRIGHT ANGEL QUADRANGLE, ARIZ.

a, Kaibab limestone; **b**, Coconino sandstone; **c**, Hermit shale; **d**, Supai formation; **e**, artificial fill below trail.

depressions in it are numerous, irregular in profile, and comparatively narrow. Some of these hollows are 40 feet deep. At Turquoise Canyon, 2½ miles from Ruby Canyon, the hollows are less numerous but are broader and deeper than they are at Ruby Canyon. Some are 80 feet deep. In profile they are irregular, like those at Ruby Canyon. At Slate Creek, 3 miles from Turquoise Canyon, the hollows are broad and deep but are more symmetrical in profile than those at Ruby Canyon. At Hermit Creek, 5 miles from Slate Creek, they are symmetrical, broad, and deep but are much less numerous than at Slate Creek. At Pipe Creek, 5½ miles from Hermit Creek, they are shallower and narrower than at Hermit Creek but otherwise resemble those at Hermit Creek. Southeast of Pipe Creek they disappear, and at Cottonwood Creek, 7 miles from Pipe Creek, the unconformity is represented by a slightly wavy surface which does not appear to exhibit vertical irregularities of more than 3 or 4 feet in horizontal distances of hundreds of feet.

In the region between Ruby Canyon and Pipe Creek the hollows look like cross sections of ancient stream valleys. If they are, I believe it would be possible by studying and mapping the hollows between Slate Creek and Ruby Canyon to identify certain ancient valleys in opposite walls of a canyon, trace them through the narrow promontories separating the canyons, and thus by restoring in imagination their courses over a considerable area determine their direction and grade.

DEVONIAN SYSTEM.

TEMPLE BUTTE LIMESTONE.

Although the upper limit of the Tonto group is clearly defined by the unconformity just described, the correlation of the beds that lie between this unconformity and the sheer cliff of the Redwall limestone is a difficult problem. The beds differ from place to place in thickness, character, and succession and are not separated from the overlying Redwall strata, of known Mississippian age, by a sharp stratigraphic break like the unconformity at the summit of the Tonto. Some beds are unquestionably of Devonian age, and others may be Mississippian, but owing to their variation in character and succession and to the absence of sharp stratigraphic breaks their separation can be established definitely only by the aid of fossils. Many beds contain obscure traces of life, but determinable forms are scarce and the beds are difficult to reach in many places where it seems desirable to study them. It will be necessary to make a more thorough study of the beds than I have yet attempted, and particularly to make a systematic search for fossils in them, before their age and correlation can be established in detail. Meanwhile the correlations presented in this report (see Pl. XX) should be regarded as tentative.

Fortunately one type of deposit that can be recognized wherever it is present by its peculiar lithologic character has yielded fossils at one locality which conclusively establish its age as Devonian. This deposit is an irregularly bedded, gnarly pinkish or purplish calcareous sandrock which fills hollows in the surface marked by the unconformity. It is exposed most typically in the canyons between Ruby Canyon and Pipe Creek (see fig. 3 and Pl. XX) and is apparently represented by equivalent beds at Garnet Canyon and at Cottonwood Creek. It is not exposed at Bass Canyon. Apparently it is the oldest deposit laid down upon the post-Tonto surface in this part of the Grand Canyon.

The locality where I found fossils in the deposit is in Sapphire Canyon, at an elevation of about 3,700 feet, in the main stream course of the canyon. At this point the deposit fills a depression about 50 feet deep eroded in the Muav limestone. It consists essentially of irregularly bedded calcareous sandrock whose component grains are chiefly calcareous or dolomitic sand; the rock might thus be classed either as limestone or as sandstone. Some beds, however, are compact crystalline limestone or dolomite, and some are coarse conglomerate. A few beds consist of bright-red fine-grained friable sandstone or sandy shale which resembles the Hermit shale higher in the canyon wall. (See p. 64.) In places this red sandstone shows concretionary structure, and some beds exhibit sun cracks. Practically all the calcareous sandrocks and associated beds are in lenticular layers which are highly irregular and are of no great horizontal extent, commonly wedging out within distances of less than 100 feet. Local unconformities are common between the beds. No two vertical sections of the deposit are alike, even in the same hollow. The prevailing color of the beds is pinkish or purplish gray, but some beds display green or yellowish tints, and some are white or cream-colored. In many places the colors are mingled in blotches and streaks. Most of the rock is moderately fine grained, and nearly all of it exhibits cross-bedded structure. In many parts of the deposit, but particularly at the top, the bedding is curiously gnarled and contorted. Probably this gnarly structure is an irregular form of cross-bedding.

The fossils occur in the lower part of the deposit, most of them within 3 feet of the base. They are abundant but are fragmentary and poorly preserved. A few fragments are scattered through higher beds. The following analysis of a representative sample of the rock in which the fossils occur shows that the rock is an impure dolomite.

Partial chemical analysis of limestone from Sapphire Canyon.

[Alfred A. Chambers, analyst.]

Insoluble	10.96
$(Al, Fe)_2O_3$	2.89
CaO	27.43
MgO	17.88

The fossils are scales and plates of fishes. The material which I collected was examined by J. W. Gidley, who writes:

> I have gone over your collection critically and find only *Bothriolepis* represented in the lot. The material is too fragmentary to be determined specifically. However, the form represented appears to agree rather more closely with an Eastern species, *B. nitidus*, found in the Catskill formation, than it does with the common western form, *B. canadensis*. This, however, is not important for your purpose, except that it certainly indicates Upper Devonian.
>
> So far as I know, *Bothriolepis* is characteristic of the Upper Devonian and is not known to occur below the Middle Devonian.
>
> In addition I may state that in the character of the rock and broken condition of the fish remains your collection is very similar to the Catskill material.

The deposits of the type just described can therefore be assigned without question to the Devonian Temple Butte limestone, which, according to Walcott,[28] "is unmistakably marked by thin purplish-colored layers of fine-grained sandstone that pass into calcareous sandrock and limestone in which cyathophylloid corals, casts of brachiopods and gastropods, and plates of placoganoid fishes usually occur." Fossils will probably be found in other localities than the one in Sapphire Canyon when systematic search is made for them.

The deposits just described are essentially similar wherever they are exposed, although they may differ somewhat in lithologic detail. At Turquoise Canyon, for example, they contain many lenses of conglomerate, whereas at many other localities they may contain little or none. At some places they may contain no bright-red sandstone or shale, and at some places little or no limestone or dolomite. Calcareous sandrock characterized by gnarly or contorted bedding, however, is always present. At Turquoise and Sapphire canyons and at the canyons of Slate and Hermit creeks the upper part of the deposits consists wholly of gnarly sandrock, which forms a massive, rather distinct bed from 20 to 25 feet thick. Commonly the upper part of this bed extends over the top of the higher Cambrian knolls to a depth of 5 to 15 feet.

At Bass Canyon the massive dolomite (subdivision A) at the top of the Muav limestone is overlain by 75 feet of thin-bedded purplish to white sandy limestone which is mottled in places by worm markings and contains a few beds of intraformational conglomerate similar to that in the Muav limestone. This thin-bedded limestone contains no determinable fossils, although one bed contains obscure forms that are probably cup corals. A detailed section of the limestone is given on pages 32–33. The following analysis shows the composition of a sample of the limestone taken from bed 14, at the base of the section:

Partial chemical analysis of limestone from bed 14, Temple Butte limestone.

[Alfred A. Chambers, analyst.]

Insoluble	24.41
$(Al, Fe)_2O_3$	1.83
CaO	22.95
MgO	15.01

The rock is therefore an impure magnesian limestone or dolomite. The insoluble impurities are probably largely quartzose sand.

The beds of sandy limestone are overlain by a massive bed of brecciated limestone (see p. 32), which lies at the base of the Redwall cliff. Both upper and lower surfaces of this brecciated limestone are wavy, but I am not sure that they represent planes of erosion. At any rate the brecciated bed marks an abrupt change in lithology, and I have placed it at the base of the Mississippian Redwall.

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[28] Walcott, C. D., Pre-Carboniferous strata in the Grand Canyon of the Colorado, Ariz.: Am. Jour. Sci., 3d ser., vol. 26, p. 438, 1883.

At most places in Bass Canyon the contact between the thin-bedded sandy limestone and the underlying massive dolomite of the Muav limestone is an even line, so that the two formations appear to be conformable. But at Garnet Canyon, 3 miles west of Bass Canyon, and at Ruby Canyon, 2 miles southeast of Bass Canyon, the thin-bedded sandy limestone is separated from the Muav by a plain line of erosion. (See fig. 3.) The contact is therefore an unconformity.

I have assigned the 75 feet of thin-bedded sandy limestone exposed at Bass Canyon to the Devonian Temple Butte limestone, because at Garnet Canyon (see Pl. XX) similar beds overlie a gnarly purplish conglomeratic sandrock that resembles the deposit in which fish remains occur in Sapphire Canyon and are overlain by other beds of gnarly conglomeratic sandrock and red shale, so that at Garnet Canyon the thin-bedded sandy limestone is actually included within beds that are lithologically identical with the known Temple Butte limestone.

POSSIBLE UNCONFORMITY BETWEEN DEVONIAN AND CARBONIFEROUS SYSTEMS.

Walcott[29] has shown that at Kanab Creek the Redwall limestone is separated from underlying Devonian beds by a line of erosion, but I am unable confidently to trace this unconformity in the region between Garnet Canyon and Cottonwood Creek and at all places to separate Devonian beds from the Redwall limestone.

At Hermit Creek the sequence of beds between the Devonian Temple Butte limestone and the Redwall strata of known Mississippian age is as follows:

Section in western slope of Cope Butte, near Hermit trail.

[For profiles of section see Pls. XIX and XX.]

	Feet.
Massive gray magnesian limestone of known Mississippian age forming lower part of sheer Redwall cliff	80±
1. Alternating beds of gray magnesian limestone, buff sandstone, and chert; partly concealed; form slope	15
2. Massive gray vesicular crystalline magnesian limestone; cavities contain coarse crystals of of calcite; forms cliff	11
3. Concealed beds; form slope	6
4. Limestone like bed 2; cliff	7
5. Band of chert layers; weathering black	1
6. Limestone like bed 2; cliff	7
7. Buff sandstone with bands of chert	5
8. Limestone like bed 2; cliff	7
9. Buff sandstone with bands of chert	2
10. Limestone like bed 2 but sandy; slope	4
11. Sandy conglomerate composed largely of fragments of calcareous sandrock; cliff; base of bed uneven, wavy	1–3
Gnarly purplish and white calcareous sandrock of known Devonian age (Temple Butte limestone) lying in hollow eroded in Muav limestone; upper surface of sandrock uneven, wavy; in places exhibits inequalities of 3 feet	14–76

The following analysis of a representative sample of the limestone forming bed 8 of the foregoing section probably shows approximately the composition of beds 2, 4, and 6 as well, because none of these beds differ in appearance.

Partial chemical analysis of limestone from bed 8, Cope Butte.

[Alfred A. Chambers, analyst.]

Insoluble	0.47
$(Al, Fe)_2O_3$	.41
CaO	31.79
MgO	19.65

The limestone is therefore a practically pure dolomite, and it is interesting to note that the chemical composition of this rock is almost exactly that of the overlying limestone, which forms the lower part of the Redwall cliff (see analysis, p. 55) and from which, indeed, the limestone of bed 8 is almost indistinguishable in appearance, differing only in the thickness of the bedding.

Because the limestones in the series of beds 1 to 11 of the above section are lithologically identical with the beds at the base of the overlying Redwall limestone I have assigned the series to the Redwall limestone. The lithologic change from these beds to the gnarly sandrock underlying them is sharp, and it is possible that the wavy line at their base marks an erosional unconformity which separates the Devonian from the Mississippian. However, I do not wish unduly to emphasize the importance of the latter feature, because wavy surfaces occur at many horizons in the Redwall and Temple Butte limestones and are not necessarily of widespread stratigraphic significance.

Massive beds of gray vesicular magnesian limestone that alternate with layers of sand or chert and are similar to the series at Hermit Creek just described are exposed at Turquoise Canyon and in the canyons of Slate, Pipe, and Cottonwood creeks, where I have also assigned them to the Redwall limestone. (See Pl. XX.) Apparently the series thickens southeastward and attains a thickness of more than 100 feet in the region about Cottonwood Creek, but I have examined it in detail only at Hermit Creek. At Turquoise Canyon and Slate Creek it is underlain by 15 to 20 feet of thin-bedded sandy purplish and whitish magnesian limestones; those at Slate Creek I have assigned tentatively to the Temple Butte limestone (see Pl. XX), because they resemble the thin-bedded Temple Butte limestone at Bass Canyon (see pp. 51–53), although it is possible that they belong at the base of the Redwall limestone, for they are separated from underlying gnarly sandrock of Devonian age by a slightly wavy surface. At Bass Canyon no beds at all resembling the massive vesicular limestones of Hermit Creek appear below the base of the Redwall cliff. The lithologic change from typical Redwall beds to the thin-bedded purplish sandy limestone of the Devonian takes place at a brecciated bed at the very base of the cliff, and the plane of separation, as stated on page 53, may or may not be an unconformity. At Garnet Canyon all beds above the known Devonian are inaccessible. An uneven surface is exposed there at the top of the highest beds that I could reach, but I do not know whether this surface is an unconformity separating Devonian and Mississippian or only a local unconformity in the Temple Butte limestone.

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[29] Walcott, C. D., The Permian and other Paleozoic groups of the Kanab Valley, Ariz.: Am. Jour. Sci., 3d ser., vol. 20, pp. 221-225, 1880.

In brief, if an unconformity separates the Temple Butte limestone and the Redwall limestone in the region which I have examined, it is so obscure and exhibits so little irregularity that it can be detected only by obtaining determinable fossils in the strata within which it lies. Certainly no surface of erosion exists which is at all comparable in irregularity with that which separates the Tonto group from overlying beds.

CARBONIFEROUS SYSTEM.

MISSISSIPPIAN SERIES.

REDWALL LIMESTONE (RESTRICTED).

Definition.—In previous publications the Redwall limestone has been classified as of Pennsylvanian and Mississippian age. As originally defined by Gilbert [30] the formation was "named from the red appearance of its escarpments on either side of the Grand Canyon" and included in its top 200 to 510 feet of alternating sandstones and limestones of "Coal Measures" (Pennsylvanian) age. Later writers have also included these Pennsylvanian beds in the Redwall, although Darton [31] in 1910 expressed the belief that they properly belonged to the overlying Supai formation. In the present report these beds of Pennsylvanian age are transferred to the Supai formation, to which, by reason of their lithology, age, and probable unconformable contact with the Mississippian rocks, they seem more properly to belong. The name Redwall limestone is therefore here restricted to the massive gray crystalline limestones of Mississippian age, and this restricted definition has been adopted by the United States Geological Survey.

Character.—The Redwall limestone as here restricted consists almost wholly of bluish-gray crystalline limestone whose distinctive features are massive appearance, hardness, and relatively great thickness. The massive appearance of the limestone is due partly to the thickness and homogeneity of the beds but chiefly to the fact that the planes of separation between many beds are inconspicuous, so that when viewed from a distance large parts of the formation present the appearance of a single stratum. The hardness and thickness of the limestone cause it to make the sheerest and most continuous cliff in the canyon wall.

At Bass Canyon the Redwall limestone is about 570 feet thick and is divisible into three parts which differ in topographic expression. Subdivision C, at the base of the formation, makes a slope that unites with the steep ledgy slope formed by the Temple Butte limestone (see p. 32) and is a bed of sandy breccia 8 feet thick whose fragments consist chiefly of gray limestone. It is overlain by bluish-gray massive crystalline limestone, obscurely bedded at the base and top, which makes a cliff approximately 500 feet high. This cliff-making limestone constitutes subdivision B. Subdivision A, at the top of the formation, consists of distinctly bedded bluish-gray crystalline limestone which includes a few thin partings of red shale. This subdivision, 62 feet thick, makes a succession of small cliffs and narrow ledges above the sheer cliff formed by subdivision B. The character and succession of the Redwall beds are described in the sections given on pages 31–32, and the profiles of the subdivisions are shown in the columnar section (Pl. XIX).

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[30] Gilbert, G. K., U. S. Geog. and Geol. Surveys W. 100th Mer. Rept., vol. 3, pp. 161, 162, 177, 178, 185, fig. 82, 1875.

[31] Darton, N. H., A reconnaissance of parts of northwestern New Mexico and northern Arizona: U. S. Geol. Survey Bull. 435, p. 22, 1910.

Subdivisions A and C can not be traced with certainty far from Bass Canyon, but subdivision B, the main cliff-making portion of the Redwall, is constant in lithology and in appearance and is readily recognizable everywhere in the Kaibab division of the Grand Canyon. The upper and lower portions of the subdivision are obscurely and heavily bedded, whereas the middle portion is distinctly bedded and contains many thin layers of chert and sand. Most beds in the subdivision contain a few scattered nodules of chert, but chert is conspicuously abundant only in the middle, distinctly bedded portion. Many beds contain coarse crystals of calcite, some of which line cavities, some of which form large irregular masses in the rock, and some of which form layers a few inches to a foot thick. Interbedded layers of sandstone occur throughout the subdivision but are numerous only in the middle portion. As a rule the sand is loosely cemented and exhibits gnarly structure. Many beds rest on irregular, wavy surfaces. In many places the limestone cliff is stained pinkish or pale rose color by ferritic pigment washed over it from overlying red shales in the Supai formation. Unstained surfaces of the limestone commonly weather gray or bluish gray. Freshly broken surfaces are gray, buff, or white.

The following analyses show the composition of representative samples of limestone from subdivision B at Bass Canyon. No. 1 represents the obscurely bedded limestone (No. 1, p. 32) that forms the upper part of the subdivision; No. 2, the heavily bedded limestone (No. 3, p. 32) that forms the lower part.

Partial chemical analyses of limestone from subdivision B, Redwall limestone.

[Alfred A. Chambers, analyst.

	1	2
Insoluble	0. 48	0. 82
$(Al, Fe)_2O_3$	. 10	. 40
CaO	55. 50	32. 54
MgO	. 08	19. 52

These analyses show that the limestone at the top of the subdivision is practically pure, whereas that at the base is magnesian and is essentially dolomite. The composition of the limestone forming the middle, laminated member of the subdivision was not determined by analysis, but inasmuch as this limestone resembles that in the overlying obscurely bedded member in appearance and effervesces freely with acid, it is probably not magnesian. The limestones in subdivision A resemble those in the upper part of subdivision B and effervesce freely with acid. It would appear, therefore, that the limestone in the whole upper portion of the Redwall is comparatively pure and only that in the basal member of subdivision B is magnesian.

Southeastward from Bass Canyon subdivision B diminishes gradually but steadily in thickness. At Bass Canyon it is approximately 500 feet thick; at Hermit Creek, 13 miles southeast of Bass Canyon, 475 feet; and at Red Canyon, 16 miles farther southeast, 375 feet. Red Canyon is 4 miles east of Cottonwood Creek. This decrease in the thickness of subdivision B is readily apparent to most observers in the diminished height of the Redwall cliff when seen from Grandview or Desert View, as contrasted with the height of the cliff when seen from the head of the Hermit trail or from Bass Camp.

Subdivision A as defined at Bass Canyon is traceable southeastward at least as far as Hermit Creek (see columnar sections, Pl. XIX), but subdivision C is not traceable southeast of Ruby Canyon, 2 miles from Bass Canyon. At Slate Creek, 8 miles southeast of Bass Canyon, and in the region southeast of Slate Creek (see Pl. XX) subdivision B is underlain by a series of gray vesicular magnesian limestones and interbedded sandstones which make a steep ledgy slope beneath the cliff of subdivision B. A section of these alternating limestones and sandstones at Hermit Creek is given on page 53. This series, which I have assigned to the Redwall limestone (see p. 53), apparently occupies a lower horizon in the Redwall than subdivision C, which actually is probably a local bed at the base of subdivision B. The alternating limestones and sandstones thicken southeastward, for they are 68 feet thick at Hermit Creek and at least 130 feet (estimated) at Red Canyon. I have not measured them at Slate, Pipe, and Cottonwood creeks.

Thickness.—The Redwall limestone decreases in thickness in the 29 miles between Bass Canyon and Red Canyon. It is 570 feet thick at Bass Canyon, 538 feet at Hermit Creek, and a little over 500 feet at Red Canyon. The decrease in thickness in the formation as a whole is not so great as the decrease in its cliff, because the series of alternating limestones and sandstones at the base of the formation increases in thickness southeastward as the overlying cliff-making limestone diminishes. At Kanab Creek, 30 miles northwest of Bass Canyon, the formation is a little over 700 feet thick. (See Pl. XIX.)

Fossils.—Fossils are scarce in the Redwall limestone at the Bass, Hermit, and Bright Angel trails. Commonly they are poorly preserved and are difficult to collect unless they are weathered out of the rock. In 1914 I made small collections at two localities. At Bass Canyon I obtained from the middle, distinctly bedded member (2) of subdivision B *Fenestella* sp. and *Schuchertella chemungensis*. This locality is at the Bass trail near the bottom of the narrow part of Bass Canyon in the Redwall.

In the canyon of Hermit Creek I obtained from the same middle member of subdivision B

Monilipora? sp.
Crinoid stems.
Fenestella, several sp.
Rhipidomella sp.
Camarotoechia sp.
Spirifer centronatus.
Syringothyris? sp.

The fossils were identified by G. H. Girty, who writes:

> Although these fossils are poor and constitute a very small fauna, they indicate with but little uncertainty a Mississippian (Madison) age and thus confirm previous determinations of the age of the lower and major part of the Redwall limestone. It is true that an undoubted Pennsylvanian fauna has been cited by Meek from the upper part of the Redwall limestone of this general region, but these fossils came from beds that are now being transferred to the Supai formation.

In 1920 I collected fossils from beds near the top of the Redwall limestone at two localities.

One collection, which I labeled lot C, I obtained at the very top of the Redwall cliff in the canyon of Garden Creek directly under El Tovar. The locality is about an eighth of a mile east of the point where the Bright Angel (Cameron) trail descends the Redwall cliff and may be reached by leaving the trail at this point and walking eastward along the narrow bench at the summit of the cliff. The fossils weather from the upper surface of the limestone that underlies this bench, and the horizon appears to be equivalent to the very top of subdivision B of the Bass Canyon section.

The other collection, which I labeled lot A, I obtained from bed 5 of subdivision A in Bass Canyon. (See p. 31.) The locality is on the west side of Bass Canyon about a quarter of a mile north of the point where the Bass trail descends the break in the Redwall cliff at the head of the canyon. It may be reached by following the first bench above the top of the sheer cliff of subdivision B that is wide enough for a man to walk upon. The fossiliferous horizon is about 14 feet above the top of the cliff.

Regarding these two collections Mr. Girty writes:

> Lot C contains an abundant fauna, though one showing but little diversity and represented by very unsatisfactory specimens. I recognize in it the following forms:
>
> Diphyphyllum? sp. (probably the same form shown by better specimen in lot A).
> Camarotoechia? n. sp.
> Spirifer centronatus.
> Spirifer aff. S. incertus.
> Composita? sp.
> Bellerophon sp.
> Euomphalus? sp.
>
> Lot A contains *Diphyphyllum* (*Lithostrotion?*) sp., *Camarotoechia?* (apparently the same form as in lot C), and a fucoid.
>
> These two lots contain essentially the same fauna and are of the same geologic age. As between Pennsylvanian and Mississippian, I should refer them with little question to the Mississippian. As between lower Mississippian and upper Mississippian—that is, as between Madison and Brazer—a definite conclusion can not be reached. So few occurrences of upper Mississippian rocks are known in this southwestern region that a general probability is established that these faunas belong to the lower horizon. The facies of the faunas corresponds so far as it goes with the lower Mississippian faunas, as we know them now, but the forms contained in these collections are so few, so poorly represented, and in some cases so ambiguous that one can not deny the existence of a possibility that the geologic age may be upper Mississippian. To state the matter briefly, as I see it, the evidence so far as it goes suggests lower Mississippian, but it does not go far enough definitely to establish the lower Mississippian age of the horizon. My personal convictions, I may add, are strong that the age is actually lower Mississippian.

Schuchert, who has collected fossils in the Redwall at the Hermit trail, states:[32]

> The base of the Redwall on the Hermit trail consists of three thick beds. The upper one is from 10 to 12 feet thick, and the lowest bed is 8 feet thick, of a vesicular gray dolomite with the cavities filled with calcite. The upper bed has *Syringopora* cf. *surcularia*. Between these two dolomite beds is a yellowish-white sandstone, 4 feet thick.[33]
>
> The Redwall may be studied on the Hermit trail below the Cathedral Stairs, but the sequence can not be made out with certainty because all of it has slumped and slid down in a huge landslide. The parts are mixed, and even some of the Supai is included with blocks of the Redwall. One entire day was devoted to collecting fossils from it, but the results were very unsatisfactory. Toward the middle of the Redwall were seen sections of a few corals, of *Menophyllum* and *Clisiophyllum*, and a number of crinoidal columnals, besides *Spirifer centronatus*. Of the few fossils taken away there is a *Syringopora* like *S. surcularia* Girty, *Menophyllum excavatum* Girty, *Fenestella* and *Polypora* in several species, and a finely striate *Spirifer*.
>
> These fossils are seen to belong to the same fauna as those identified by Girty from near Nelson, Ariz., and collected by W. T. Lee. The time indicated by them is that of the Madison limestone so widely distributed in the Rocky Mountain country, or of the older half of the Mississippian of the Mississippi Valley.

In 1879 Walcott collected fossils at Kanab Creek at many horizons in beds which he designated subdivisions b and c of the Redwall limestone. (See Pl. XIX.) These two subdivisions and the underlying subdivision d of Walcott's section correspond closely in lithology with the Redwall of my Bass Canyon section and constitute the Redwall as it is here redefined. Subdivision a, at the top of Walcott's Redwall at Kanab Creek, corresponds in lithology to my subdivision C of the Supai formation at Bass Canyon and undoubtedly properly belongs in the Supai. (See p. 62.)

These collections from subdivisions b and c at Kanab Creek were never worked up in detail by Walcott and in the course of time have become badly mixed with collections made from other Carboniferous beds in the general region. However, Mr. Girty, who has examined the material, makes the following statement concerning as much of it as he is able to assign to the collections from b and c:

> The faunas are much more extensive and conclusive than the one contained in your lots A and C, and I refer them without hesitation to the lower Mississippian, to that widespread limestone formation which has commonly been called the Madison limestone but which in New Mexico has received the name Lake Valley limestone. I do not myself feel in doubt, although the evidence is not entirely conclusive, that the entire Redwall limestone, so far as it is embraced within the horizons represented by your collections A and C and by Mr. Walcott's collections from Kanab Canyon, is of lower Mississippian age and belongs in a general alinement with the Madison limestone.

The type locality of the Redwall limestone selected by Darton[34] is Redwall Canyon, in the Shinumo Amphitheater, only 4 miles north of Bass Canyon. The section at Bass Canyon, given in the present report, is so near Redwall Canyon that it may be assumed practically to represent the formation at the type locality. The evidence just presented indicates that at the type locality the entire Redwall as here restricted is of lower Mississippian age, although it is conceivable, but highly improbable, as Girty states, that the beds at the top of the formation in which I found fossils may be upper Mississippian.

No evidence has been found which indicates that any part of the Redwall as here recognized in the Kaibab division of the Grand Canyon is younger than Mississippian.

Ransome,[35] who has examined the Redwall in the Jerome region, where he collected fossils in it that Girty identified as lower Mississippian, states: "No evidence was obtained at Jerome to indicate that any of the Redwall limestone is as young as the Pennsylvanian." In the Jerome region the beds assigned to the Redwall aggregate only 250 feet and probably belong to the lower part of the formation.

PROBABLE UNCONFORMITY BETWEEN MISSISSIPPIAN AND PENNSYLVANIAN SERIES.

The top of the Redwall limestone is very difficult to reach, except at places near the trails that descend the canyon wall, and I have so far been able to examine it only at the Bass trail, at the trail which ascends the northern wall of the Grand Canyon through Muav Canyon, and at the Hermit, Bright Angel, and Hance (Red Canyon) trails. Viewed from a distance it appears to exhibit no irregularity at most places in the Kaibab division of the canyon.

At Bass Canyon the contact between the typical bluish-gray limestone of the Redwall and the red shale at the base of the overlying Supai appears to be remarkably even, and the only evidence of a stratigraphic break is the abrupt change from limestone to shale. However, actual exposures of the contact are not to be found, owing to the softness of the shale, which makes a slope at this horizon that is entirely concealed by talus.

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[32] Schuchert, Charles, op. cit., pp. 360-361.

[33] The three dolomite beds described by Schuchert are probably beds 2, 4 to 6, and 8 of my section at Cope Butte given on page 53.—L. F. N.

[34] Darton, N. H., A reconnaissance of parts of northwestern New Mexico and northern Arizona: U. S. Geol. Survey Bull. 435, p. 21, 1910.

[35] Ransome, F. L., Some Paleozoic sections in Arizona and their correlation: U. S. Geol. Survey Prof. Paper 98, p. 162, 1916.

At Muav Canyon the surface of the Redwall is uneven, but the beds are shattered along the axis of a faulted flexure, so that it is uncertain whether the unevenness is due to shattering or to erosion.

At the Hermit, Bright Angel (Cameron), and Hance trails the appearance of the top of the Redwall suggests that it was exposed to erosion before the overlying Supai beds were deposited, as I shall show.

Near the Hermit trail, just south of the point where the trail descends the Redwall, the upper surface of the Redwall limestone is decidedly uneven, and in places jagged knolls of the limestone project 25 feet or more above the general level of the surface. At this locality the basal deposit of the Supai is a bright reddish or purplish sandy shale. Some parts of the shale exhibit no bedded structure whatever; other parts exhibit gnarly, irregular bedding and are more or less concretionary, whereas still other parts are evenly and thinly bedded. Thin lenses of conglomerate occur at some horizons in the shale. The pebbles in the conglomerate are well rounded and are coated with black "desert varnish." Most of them are composed of chert, derived, apparently, from the underlying limestone. The shale varies considerably in thickness from place to place. Above the tops of the higher limestone knolls the thickness may not exceed 45 feet, but between the knolls, where the deposit appears to fill depressions, the thickness may exceed 70 feet. The deposit becomes more evenly bedded toward the top, and the upper 21 feet consists of thinly laminated soft reddish shale. Above this shale are alternating beds of red sandy shale, purplish and gray limestone containing red chert, and reddish to buff calcareous sandstone. The thickness of these alternating beds is 132 feet. The section just described, 202 feet in total thickness, is shown diagrammatically on Plate XIX. The beds are undoubtedly equivalent to subdivision C of the Supai at the Bass trail. (See p. 61.) The upper surface of the Redwall limestone is infiltrated with red mud, and the overlying irregularly bedded, more or less structureless red shale appears to represent just such a deposit of red clay as one would expect to find above a weathered limestone surface. It is possible that the roughness of the top of the Redwall is due to shattering of the beds in this locality, because the formation has slumped in a landslide at the point where the trail descends it. For this reason the evidence just presented should be regarded as inconclusive. Nevertheless the lithologic change from the massive limestone of the Redwall to the structureless red deposit above it is so sharp that it indicates a stratigraphic break at this horizon, and the variation in thickness of the red shale is also suggestive. The bed is 72 feet thick at the Hermit trail, whereas the shale at the corresponding horizon in Bass Canyon is not over 1[illegible] feet thick. (See p. 31; also Pl. XIX.)

At the Bright Angel (Cameron) trail the summit of the Redwall is irregular, but here also the evidence is inconclusive, because the Redwall is shattered by a fault in the vicinity of the trail.

At Red Canyon the summit of the Redwall is well exposed near the 4,955-foot bench mark, where the Hance trail descends the Redwall on the east side of the canyon. This locality is some distance east of a fault that coincides with the axis of Red Canyon, so that the beds here have not been disturbed by the fault. Near the bench mark the surface of the Redwall is wavy, and the limestone is more or less infiltrated with red mud, but the best evidence of a stratigraphic break at the top of the limestone is found in the lithologic character of the overlying Supai beds. The Supai begins abruptly with a bed of conglomerate, which exhibits great variations in thickness. At one place it is 20 feet thick, at many places 5 to 10 feet thick, and at some places entirely absent. The conglomerate contains both angular and rounded pebbles of chert and limestone, derived, apparently, from the underlying Redwall. The pebbles range in diameter from a fraction of an inch to 6 inches but average about half an inch. The conglomerate is gravelly and contains very little matrix. Where present the matrix consists of red sandy clay. Where the conglomerate is thickest it appears to fill shallow depressions in the Redwall. Above the conglomerate is 100 feet of red friable sandy shale that is more or less calcareous and in places exhibits concretionary structure, and above the shale are alternating beds of shale, limestone containing red chert, and calcareous sandstone, some of which is cross-bedded. The conglomerate, red shale, and overlying alternating beds just described are undoubtedly equivalent to subdivision C of the Supai as exposed at the Hermit and Bass trails.

Walcott,[36] in describing the upper part of the Redwall at Kanab Creek, states:

> Toward the close of the 700 feet of limestone and its intercalated cherty bands evidences of an approaching change occur. The horizontal bedding is broken by gradually increasing curves of depression and elevation of the previously level surface. The limestone becomes more and more interstratified with white chert, weathering black. Arenaceous layers of a detrital origin come in, with pink chert and chalcedony replacing the white chert of the beds beneath.
>
> Massive layers of brecciated chert in a quartzitic matrix denote the increasing change of conditions, and soon the sandstone epoch of the Lower Aubrey group opens. The transition beds (a) have filled the hollows and leveled off the uneven surface of the limestone beneath, and, 255 feet above, the great sandstone group begins with a massive cross-bedded sandstone stratum (e), 50 feet in thickness.

The transition beds to which Walcott refers are the beds that constitute subdivision a of his Redwall at Kanab Creek (see Pl. XIX), which is now transferred to the Supai (see p. 62). Therefore the uneven surface which he describes actually lies at the top of the Redwall limestone as here restricted, and the horizon occupied by the uneven surface is equivalent to that at the Hermit, Bright Angel (Cameron), and Hance trails which I have just described.

Schuchert,[37] who has examined the Redwall-Supai contact on the Hermit trail, writes:

> The contact may be studied just beneath the signpost "Cathedral Stairs" that stands on Supai strata. It is of the disconformable type, and the Redwall is more or less eroded. Where the contact was studied this limestone-dolomite series terminates in thin-bedded deposits, with the beds varying in thickness from 12 to 20 inches. The Supai begins at once with its characteristic sandy and rain-pitted shales and muddy sandstones. This disconformity has far greater significance than the physical phenomena as seen on the Hermit trail would seem to indicate, for the fossils of the Redwall are here all of early Mississippian age. Nothing of later Mississippian time is present, and the land interval preceding Supai deposition was certainly longer than all of Redwall time.

Ransome [38] reports that 8 miles north of Jerome what he regards as the base of the Supai is a limestone conglomerate 2 to 3 feet thick in which the pebbles are generally less than 2 inches in diameter. He states that layers of a similar conglomerate also occur a little higher in the formation.

In brief, although the evidence just presented is inconclusive, it establishes a strong probability that the upper limit of the Redwall is an unconformity of erosion.

PENNSYLVANIAN AND PERMIAN (?) ROCKS.

SUPAI FORMATION (REDEFINED).

Definition.—As originally defined by Darton [39] the name Supai formation was applied to about 800 feet of red sandstones and shales, the latter in part sandy, underlying the Coconino sandstone, overlying the Redwall limestone, and composing the lower part of the Aubrey group in northern Arizona. Darton's Redwall limestone, like Gilbert's and Walcott's Redwall, included rocks of Mississippian and Pennsylvanian age. In this report the Supai formation is redefined by cutting off at the top about 300 feet of deep brick-red sandy shale and fine-grained friable sandstone of Permian age, to which the new name Hermit shale is herein applied, and by adding at the bottom about 250 feet of red sandy shale, purplish and gray limestone with red chert, and reddish to buff calcareous sandstone of Pennsylvanian age that have heretofore been included in the Redwall limestone. This redefinition of the Supai formation has been adopted by the United States Geological Survey. As thus defined the Supai formation is of Pennsylvanian and Permian (?) age and rests with probable unconformity on the underlying Mississippian Redwall limestone. The accompanying table shows the different classifications of the Carboniferous rocks of the Grand Canyon.

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[36] Walcott, C. D., unpublished notes.

[37] Schuchert, Charles, op. cit., p. 358.

[38] Ransome, F. L., op. cit., p. 162.

[39] Darton, N. H., A reconnaissance of parts of northwestern New Mexico and northern Arizona: U. S. Geol. Survey Bull. 435, pp. 25–27, 1910.

Classifications of the Carboniferous rocks of the Grand Canyon.

G. K. Gilbert, 1875. (U. S. Geog. and Geol. Surveys W. 100th Mer. Rept., vol. 3, pp. 151-186, fig. 82.)		C. D. Walcott, 1880. (Am. Jour. Sci., 3d ser., vol. 20, pp. 221-225.)	N. H. Darton, 1910. (U. S. Geol. Survey Bull. 435.)	L. F. Noble, 1922. (This report.)	Age.
Aubrey group.	Cherty limestone, 200-820 feet.	Upper Aubrey.	Kaibab limestone.	Kaibab limestone.	**Permian.**
	Cross-bedded and other sandstones, 300-1,000 feet.	Lower Aubrey.	Coconino sandstone.	Coconino sandstone.	
	Red and white shales and sandstones, 800 feet.		Supai formation.	Hermit shale. -Unconformity-	
Redwall limestone group.	Alternating sandstones and compact limestones, 200-500 feet.	Redwall limestone.	Redwall limestone.	Supai formation (redefined). -Unconformity (?)-	**Permian (?) and Pennsylvanian.**
	Redwall limestone, sheer escarpment, 800 feet.			Redwall limestone (restricted to Mississippian limestones).	**Mississippian.**
	Limestones in lesser escarpments and calcareous shales, 800-1,365 feet.				

Character of beds.—The Supai formation as here redefined consists chiefly of sandstone but includes many beds of sandy shale and a few beds of limestone. Much of the sandstone is in thick, massive beds that make strong cliffs. The shales and beds of laminated sandstone make slopes. As seen from a distance, the distinctive features of the formation are its prevailingly red color and its steplike profile, which consists of a succession of cliffs and slopes carved from the alternating hard and soft beds. Close inspection shows that the red color of the formation is derived from the shales. The outcrops of the sandstones are stained reddish by ferritic pigment washed over them from the interbedded shales, but the natural color of the sandstones, as shown on freshly broken surfaces, is buff or pinkish buff.

The sandstones of the Supai are uniformly fine grained. Some of them are regularly bedded and exhibit thin, platy lamination, but most of them are conspicuously cross-bedded, and in the thicker layers the cross-bedded structure is on a coarse scale. In uniform fineness of grain and in coarseness of cross-bedding the more massive layers resemble the Coconino sandstone. Commonly, however, their grains are bound together by calcareous cement, whereas the binding material in the Coconino is siliceous. Curiously, the prevailing dip of the inclined laminae in the cross-bedded sandstones of the Supai is south, just as it is in the Coconino. Most of the shale in the Supai resembles that of the overlying Hermit shale and is essentially a red sandy mud. Some beds exhibit sun cracks and ripple marks, but these features are not conspicuous at the Bass trail. Two types of limestone occur in the Supai. One type, which is clearly of detrital origin, consists of grains of calcareous sand, exhibits faint cross-bedded structure on weathered surfaces, and in places passes into cross-bedded sandstone. Some beds of this type are crystalline, and others granular; most of them are pinkish buff. The other type of limestone is bluish or purplish gray, massive, and crystalline and contains nodules of red chert. Beds of this type occur only in the lower third of the Supai. Many of them resemble the limestone in the underlying Redwall.

Subdivisions.—At Bass Canyon I have divided the Supai into three members, which in lithology and in topographic expression are sufficiently constant to be recognizable throughout the Kaibab division of the Grand Canyon. These members I have designated subdivisions A, B, and C.

Near the top and just below the middle of the Supai the cross-bedded sandstones are exceptionally thick and massive and make strong, conspicuous cliffs. Between these two sets of cliffs and below them the strata make steep ledgy slopes. The strata that make the upper set of cliffs constitute subdivision A; those that make the lower set of cliffs and the ledgy slope above the cliffs constitute subdivision B; and those that make the slope at the base of the Supai constitute subdivision C.

Subdivision A consists chiefly of sandstone but includes a few beds of sandy shale; subdivision B consists chiefly of sandstone but includes beds of sandy shale and a few beds of limestone; and subdivision C consists of sandstone, shale, and limestone in about equal proportions. Broadly, therefore, although the Supai consists chiefly of sandstone, it exhibits a passage upward from shale and limestone to sandstone.

Subdivisions A and B rest on slightly wavy surfaces at Bass Canyon. However, similar wavy surfaces occur at other horizons in the Supai (see sections of subdivisions B and C, pp. 29–31), and some of these surfaces are more irregular than those at the base of subdivisions A and B. Without further study it is impossible to determine whether any of them have widespread stratigraphic significance.

The order, character, and thickness of the strata that constitute the three subdivisions just outlined are described in the section of the Supai given on pages 29–31, and the topographic profile of the beds is shown in the columnar section, Plate XIX.

Subdivision C, at the base of the Supai, 208 feet thick, begins at the bottom with alternating beds of red sandy shale and bluish-gray limestone carrying nodules of red chert, and the shales and limestones pass upward into alternating beds of red shale, bluish-gray limestone, and reddish to buff calcareous sandstone, a part of which is cross-bedded. The limestones and harder sandstones form small cliffs, and the shales and softer sandstones form slopes. Outcrops of many softer beds are concealed by talus. The contact between this subdivision and the underlying Redwall limestone is described on pages 57–59, where I have presented evidence indicating that it is a plane of unconformity by erosion.

Subdivision B, the middle member of the Supai, 439 feet thick, begins at the base with heavy, cliff-making beds of buff cross-bedded sandstone, 200 feet in aggregate thickness, which are separated by thin layers of limestone or red shale. These massive sandstones pass upward into alternating beds of red friable shaly sandstone and cross-bedded calcareous sandstone that contain thin interbedded layers of limestone and, 66 feet below the top of the subdivision, a prominent bed of limestone conglomerate 28 feet thick. This conglomerate (see p. 30), which occurs in highly lenticular layers and consists chiefly of rounded pebbles of limestone embedded in a matrix of red sandy mud, appears to be continuously traceable not only through the Kaibab division of the canyon but far beyond. I have noted it on the Bright Angel (Cameron) and Tanner trails, respectively 18 and 32 miles southeast of Bass Canyon, and in the Aubrey Cliff, near Seligman, 70 miles southwest of Bass Canyon. At all these localities the conglomerate occupies approximately the same horizon in the Supai that it does at Bass Canyon. At the Bass trail and the Bright Angel trail it rests on an uneven surface which exhibits vertical irregularities of several feet within horizontal distances of 100 feet. It is conceivable that the conglomerate marks a stratigraphic break in the Supai that is more significant than the contact between subdivisions A and B.

Near Pine, in the Jerome region, Ransome[40] has noted a bed of limestone conglomerate in what he regards as the Supai at a horizon about 450 feet above the base of the formation. The conglomerate is 12 feet thick and overlies a seam of impure lignite.

Subdivision A, at the top of the Supai, 306 feet thick, begins at the base with massive beds of pinkish, purplish, or buff cross-bedded sandstone which form a set of cliffs nearly 200 feet in height. Above these sandstones are alternating beds of soft red platy sandstone and hard buff cross-bedded sandstone which form a series of cliffs and slopes.

At the top of subdivision A is a broad red platform known as the Esplanade, which begins at Bass Canyon and extends far westward in the interior of the Grand Canyon. I have described this platform in a previous report[41] and have shown that, like every other ledge in the canyon wall, it is a structural bench determined by the hardness of the beds that underlie it and the softness of the beds that overlie it, and that it does not necessarily, as Dutton supposed,[42] represent a temporary base-level of erosion produced by a pause in the uplift of the region during the cutting of the Grand Canyon. West of Bass Canyon the Esplanade is so broad that it is by far the most striking feature in the canyon landscape. East of Bass Canyon it shrinks to a narrow ledge and is inconspicuous as a topographic feature but is nevertheless traceable continuously through the Kaibab division. Inasmuch as this bench is cut on the summit beds of the Supai it constitutes a landmark that enables the observer everywhere to distinguish the Supai formation from the overlying Hermit shale. In the region between Bass Canyon and the Hermit trail it marks a conspicuous unconformity between the Supai formation and the Hermit shale. (See pp. 63–64.)

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[40] Ransome, F. L., op. cit., p. 160.

Fossils.—No determinable fossils have been found in the Supai formation in the Kaibab division of the Grand Canyon. The available evidence concerning its age may be summed up as follows:

Subdivision a of Walcott's Redwall at Kanab Creek (see Pl. XIX), "arenaceous beds with pink chert passing down into shaly limestone, brecciated arenaceous cherty beds, and gray limestone with red chert," not only corresponds closely with subdivision C of the Supai as I have defined the formation at Bass Canyon but is overlain at Kanab Creek by massive cross-bedded sandstone (subdivision e of Walcott's "Lower Aubrey group") that corresponds to the massive sandstone at the base of subdivision B of the Supai at Bass Canyon and is underlain at Kanab Creek by massive limestone which is obviously equivalent to the upper part of the Redwall as defined at Bass Canyon. Therefore there can be no reasonable doubt that subdivision a of Walcott's Redwall is subdivision C of the Supai as here redefined. Subdivision a of Walcott's Redwall is division 5 of Gilbert's Paleozoic section at Kanab Creek, "purple and white arenaceous limestone with pink chert, in one bed passing into cross-bedded sandstone." Walcott[43] states that although at Kanab Creek he obtained no fossils from these beds nor from any part of the overlying sandstones, "the beds elsewhere have given evidence of their upper Carboniferous age by the presence of a fauna rich in many species." This fauna is the Pennsylvanian fauna described by Meek and listed by Gilbert,[44] who says concerning it: "The fauna of the upper portion [of the Redwall] is rich in species and, while differing from that of the Aubrey limestone, is equally referable to the Coal Measures." By the "upper portion of the Redwall" Gilbert means not the upper portion of the Redwall as the formation is here restricted, but the beds that constitute division 5 of his section at Kanab Creek[45] and division 4 of his section at the mouth of the Grand Canyon,[45] which are equivalent to the lower part of the Supai as here defined. Recently Longwell[46] has found Pennsylvanian fossils in the Grand Wash Cliffs north of the mouth of the Grand Canyon "near the top of beds which apparently correspond to Noble's basal Supai in the Grand Canyon."

The evidence just presented indicates that subdivision C, at least, of the Supai is of Pennsylvanian age. The Supai is overlain by the Hermit shale, which contains Permian fossils, and the two formations are separated by an unconformity of erosion, but inasmuch as no determinable fossils have been found in subdivisions A and B of the Supai there is no conclusive evidence that the unconformity separates Pennsylvanian and Permian beds. Therefore the Pennsylvanian-Permian contact may lie at any horizon in the Supai between the summit of the formation and the base of subdivision B. However, no stratigraphic break as great as the unconformity at the base of the Hermit shale appears to occur within the Supai itself, so I am inclined to regard the entire Supai as probably of Pennsylvanian age.

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[41] Noble, L. F., U. S. Geol. Survey Bull. 549, pp. 21, 73–75, 1914.

[42] Dutton, C. E., Tertiary history of the Grand Canyon district: U. S. Geol. Survey Mon. 2, p. 121, 1882.

[43] Walcott, C. D., unpublished notes.

[44] Gilbert, G. K., U. S. Geog. and Geol. Surveys W. 100th Mer. Rept., vol. 3, pt. 1, p. 178, 1875.

[45] Idem, p. 162.

[46] Longwell, C. R., Geology of the Muddy Mountains, Nev., with a section to the Grand Wash Cliffs in western Arizona: Am. Jour. Sci., 4th ser., vol. 50, p. 47, 1921.

Robinson[47] has reported Pennsylvanian fossils from the Redwall limestone at Elden Mountain, near Flagstaff. He states that at this locality "the limestone becomes thinner bedded than usual and gives way to red calcareous shale and sandstone. The limestone immediately overlying these beds contains many fragments of shale and includes at one point a patch of conglomerate." The fossils determined as Pennsylvanian came "from the uppermost strata" at this locality. In my opinion, Robinson's description of the beds indicates that they are equivalent to strata exposed in the basal part of the Supai in the Grand Canyon, and not to any part of the Redwall limestone as here restricted.

Lee[48] has also reported a Pennsylvanian fauna from the top of the Redwall limestone in Truxton Canyon, near Yampai. The fossils are stated to have been obtained "near the top of the exposed section." Probably the limestone beds in which Lee found the Pennsylvanian fossils are also correlatives of limestones that lie in the basal part of the Supai at Bass Canyon.

UNCONFORMITY BETWEEN SUPAI AND HERMIT FORMATIONS.

In Hermit Basin, 12 miles southeast of Bass Canyon, a strong unconformity of erosion separates the Supai formation as here redefined from the overlying red sandy shale here named the Hermit shale. The unconformity is beautifully exposed on the Hermit trail just under a signpost marked "Red Top." (See Pl. XXIII, *B.*) At this locality the top of subdivision A of the Supai consists of alternating beds of hard pinkish or buff cross-bedded sandstone and friable red platy sandstone. These beds make a succession of small cliffs and ledges just under the bench that forms the floor of Hermit Basin and locally represents the Esplanade platform. Just under the "Red Top" sign a sharp hollow 40 feet deep in these Supai beds is filled with the soft red sandy layers that constitute the Hermit shale. The soft Hermit shale in the hollow determines a break in the small cliffs at the top of the Supai, and the trail takes advantage of this break to descend the cliffs to a ledge on the summit of the massive sandstone that forms the main cliff of subdivision A. When the observer has examined the unconformity in the fine exposure under Red Top he will have no difficulty in following it with his eye all around the rim of the canyon of Hermit Creek, where it is in plain sight for several miles. The unconformity marks the change from the highest cliff-making strata in the Supai to the softer, shaly beds that overlie them. It is difficult to recognize the unconformity at first sight because the beds above and below it are stained the same color, a deep brick-red. Many fine exposures of the unconformity may, however, be studied by following the trail that leads westward along the general level of the Esplanade from Red Top to Dripping Spring. The sketch in figure 4, *a*, and the photograph reproduced in Plate XXIV, *A*, show an exposure of the unconformity on this trail at a point about a quarter of a mile west of Red Top. As seen in the canyon of Hermit Creek the unconformity is comparable in irregularity to the unconformity at the top of the Tonto (see pp. 49–51), which, indeed, it strongly resembles, the eroded surface exhibiting in places irregularities of 50 feet or more.

I discovered the unconformity in 1916 at the end of a field trip when I came out of the canyon over the Hermit trail, and I furnished Prof. Schuchert with a sketch of it which he published in his paper on the Carboniferous formations of the Grand Canyon in 1918.[49] However, until 1920 I had no opportunity to examine the horizon of the unconformity at other localities, to learn something of its extent, but in the fall of that year I was able to examine it at several points in the south wall of the Grand Canyon northwest and southeast of Hermit Creek. Northwest of Hermit Creek the unconformity is traceable at least 11 miles, being plainly recognizable from the rim of the Grand Canyon in the walls of Ruby Canyon, 2 miles southeast of Bass Canyon. Figure 4, *b*, shows it just under Havasupai Point, the end of the promontory that forms the west wall of the Ruby Canyon. The sketch was drawn from the Grand Scenic Divide, a spur of the Esplanade a mile west of Havasupai Point, and may be incorrect in detail, for I could not reach and examine the locality shown by the sketch. At Bass Canyon

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[47] Robinson, H. H., The San Franciscan volcanic field, Ariz.: U. S. Geol. Survey Prof. Paper 76, pp. 21-22, 1913.

[48] Lee, W. T., Geologic reconnaisance of a part of western Arizona: U. S. Geol. Survey Bull. 352, p. 15, 1908.

[49] Schuchert, Charles, op. cit., p. 356.

I could not detect the unconformity, but the beds at its horizon are poorly exposed at that locality.

At the Bright Angel (Cameron) trail, 5 miles southeast of Hermit Creek, the unconformity can be detected by very careful inspection, but the eroded surface exhibits so little relief that it would probably be unrecognizable to one who had not first examined it at the Hermit trail. At Tanner Canyon, 20 miles southeast of the Hermit trail, I could not detect it. In that region the Hermit shale is readily distinguishable from the underlying Supai formation both topographically and lithologically, but the contact with the Supai is so even that if it represents an unconformity of erosion the eroded surface is practically level.

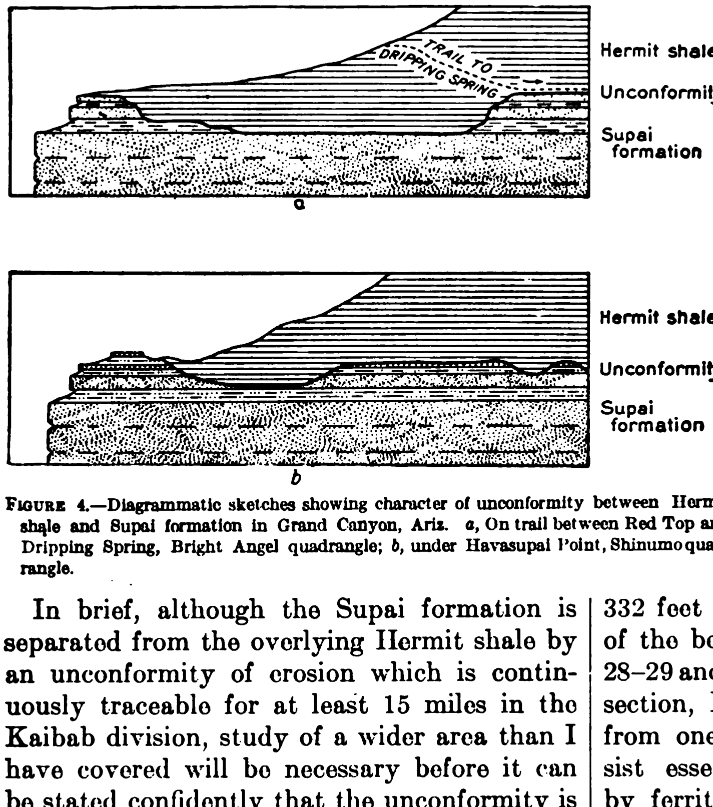

FIGURE 4.—Diagrammatic sketches showing character of unconformity between Hermit shale and Supai formation in Grand Canyon, Ariz. *a*, On trail between Red Top and Dripping Spring, Bright Angel quadrangle; *b*, under Havasupai Point, Shinumo quadrangle.

In brief, although the Supai formation is separated from the overlying Hermit shale by an unconformity of erosion which is continuously traceable for at least 15 miles in the Kaibab division, study of a wider area than I have covered will be necessary before it can be stated confidently that the unconformity is a widespread feature in the Grand Canyon district.

In the area which I have covered the unconformity coincides with the general level of the Esplanade. If this association is significant, the unconformity may extend over a very wide area, for the Esplanade extends many miles west of the Kaibab division in the Grand Canyon.

PERMIAN SERIES.

HERMIT SHALE.

Definition.—At Hermit Basin above the unconformity just described there is a series of deep brick-red sandy shales and fine-grained friable sandstones whose thickness is 317 feet measured from the base of the deepest depression and 267 feet measured from the summit of the highest knoll in the unconformity. (See Pl. XIX.) Formerly these strata were included in the Supai formation and were designated "shale of the Supai formation" or "Upper Supai shale,"[50] but because they have been found to be separated from the underlying beds by an unconformity, because they contain determinable fossils of Permian age, and because they are constant in lithology and are distinct from the underlying beds in topographic expression everywhere in the Kaibab division, I have proposed that they be designated the Hermit shale, and the name has been adopted by the United States Geological Survey. The name is taken from Hermit Basin, where the beds are typically exposed. The formation is conformably overlain by the Coconino sandstone. Plate XXIV, *B*, shows an exposure of the Hermit shale in Tapeats Amphitheater, northwest of Powell Plateau.

Character and thickness.—At Bass Canyon the Hermit shale is 332 feet thick. The character and succession of the beds are given in the section on pages 28–29 and their profile is shown in the columnar section, Plate XIX. The beds differ little from one another in composition and consist essentially of sandy mud colored red by ferritic pigment. The beds that I have designated sandstone in the section are massive and relatively compact as contrasted with the beds that I have designated shale, which are thinly laminated, but the distinction between sandstone and shale is unimportant. All the strata are friable. Many beds exhibit sun cracks and rain prints, and some beds are ripple-marked. One bed (No. 15, p. 29) con-

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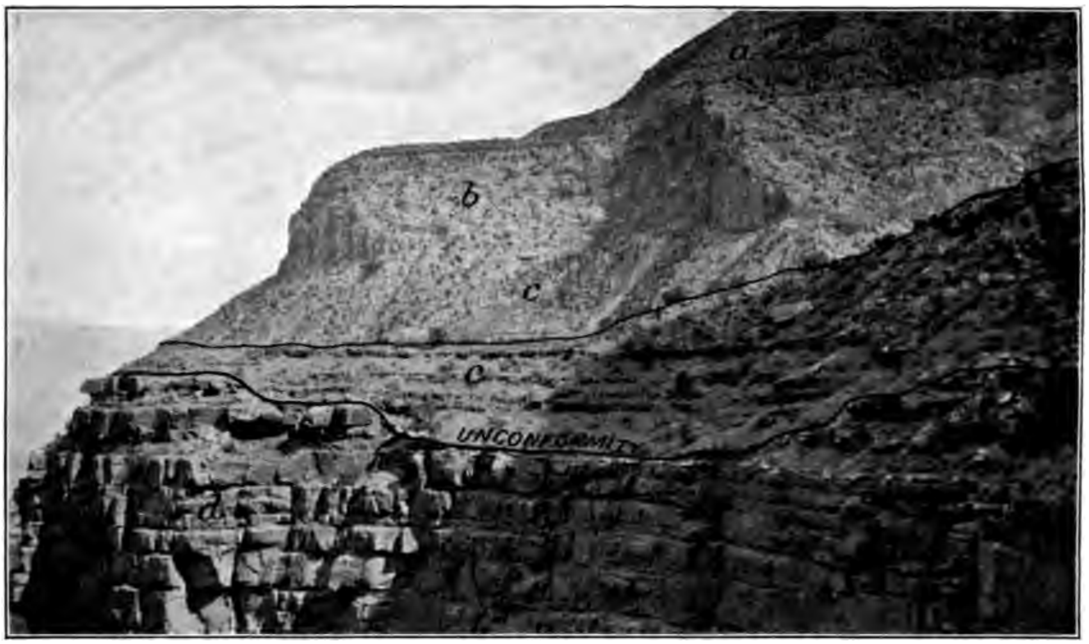
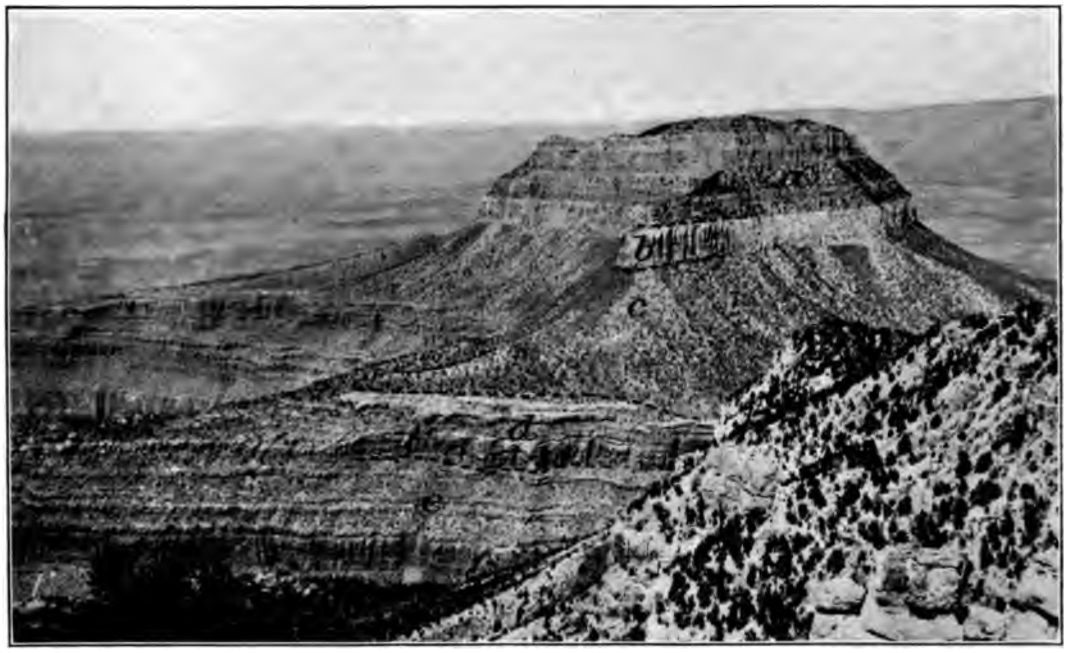
[50] Noble, L. F., op. cit., p. 69.



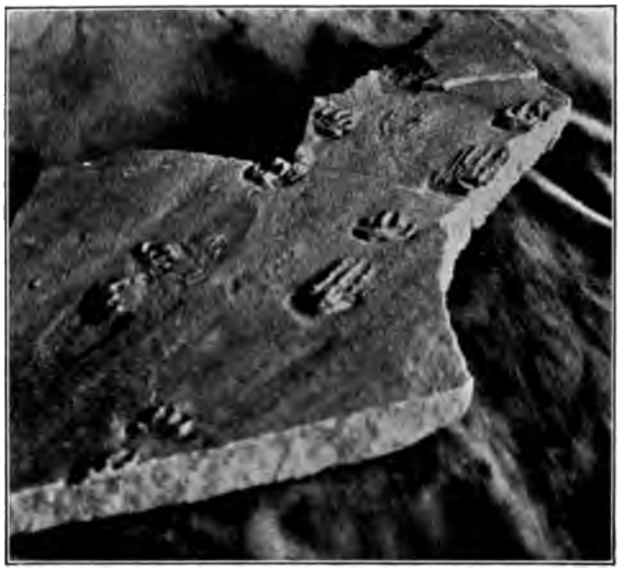
A. UNCONFORMITY BETWEEN HERMIT SHALE AND SUPAI FORMATION ON TRAIL BETWEEN RED TOP AND DRIPPING SPRING, BRIGHT ANGEL QUADRANGLE, ARIZ.

a, Kaibab limestone; *b*, Coconino sandstone; *c*, Hermit shale; *d*, Supai formation.

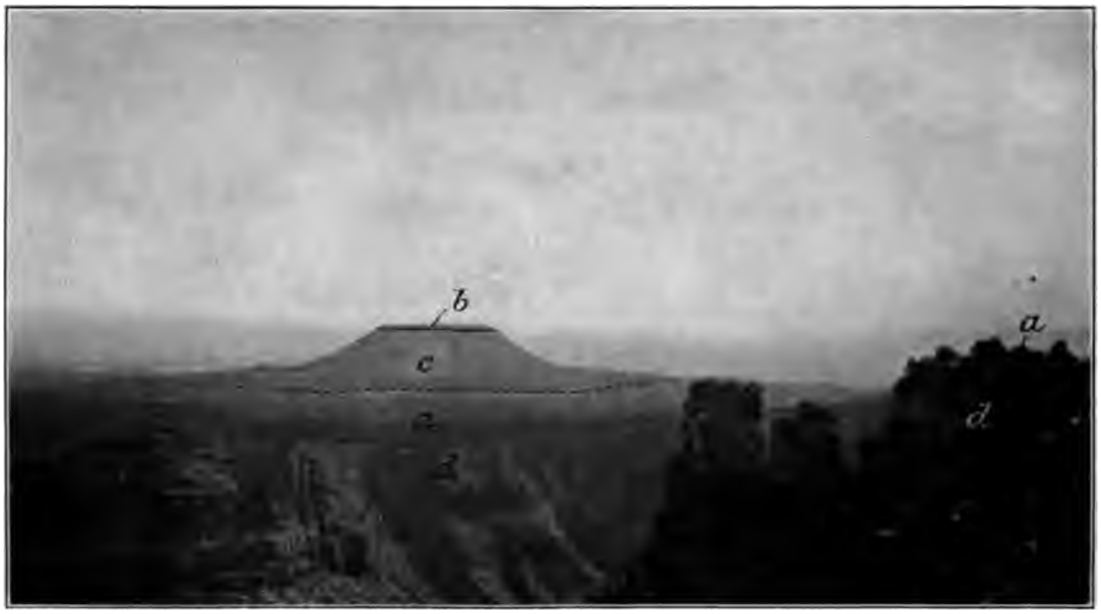


B. TYPICAL EXPOSURE OF HERMIT SHALE IN TAPEATS AMPHITHEATER, NORTHEAST OF POWELL PLATEAU, KAIBAB QUADRANGLE, ARIZ.

a, Kaibab limestone; *b*, Coconino sandstone; *c*, Hermit shale; *d*, *e*, *f*, subdivisions A, B, C of Supai formation.



A. FOSSIL TRACKS ON SLAB OF COCONINO SANDSTONE AT HERMIT TRAIL, BRIGHT ANGEL QUADRANGLE, ARIZ.



B. CEDAR MOUNTAIN, VISHNU QUADRANGLE, ARIZ., FROM DESERT VIEW CAMP.

a, Surface of Coconino Plateau; *b*, Shinarump conglomerate, capping Cedar Mountain; *c*, Moenkopi formation; *d*, Kaibab limestone.

sists of intraformational conglomerate. Near the top of the formation many beds exhibit concretionary structure. Lithologically the Hermit shale resembles many beds of sandy shale in the Supai, but unlike the Supai it contains no massive hard layers of cross-bedded sandstone, and the more sandy beds in the Hermit are prevailingly reddish, not buff, as they are in the Supai. Thin, platy lamination is the most prominent structural characteristic of the Hermit shale. Everwhere the formation makes a slope which is in strong topographic contrast with the sheer cliff of the overlying Coconino sandstone and with the steplike cliffs and ledges of the underlying Supai.

Although the Hermit shale is constant in lithology throughout the Kaibab division of the Grand Canyon its thickness varies considerably. In the region about Tanner Canyon, in the eastern part of the Kaibab division, it is less than 100 feet thick (estimated) and may be less than 75 feet. At Bass Canyon it is 332 feet thick, and west of Bass Canyon, at the west end of the Kaibab division, more than 500 feet. The widening of the Esplanade west of Bass Canyon is caused, as I have shown,[51] by the increase in thickness of the soft Hermit shale, which wastes back from the floor of the platform, in conjunction with a corresponding shrinkage in the overlying hard Coconino sandstone, which defends the retreat of the wall above the platform. Apparently the Hermit shale continues to increase in thickness at least as far as Kanab Creek, for Walcott's subdivisions a1, a2, and a3 of the Aubrey group at Kanab Creek, which I believe represent the Hermit shale, are 775 feet in aggregate thickness. (See Pl. XIX.)

Beds in Gilbert's section at the mouth of the Grand Canyon,[52] which he designates division 3 and which may represent the Hermit shale, are said to be 800 feet thick at that locality.

In the Aubrey cliff 4 miles north of Seligman beds identical in lithology with the typical Hermit shale underlie the Coconino sandstone and overlie a cliff-making portion of the Supai that corresponds in lithology and in stratigraphic position to subdivision A of the Supai as defined at Bass Canyon. The beds between the Supai and Coconino formations are 80 feet thick, are soft and thinly laminated, and make a slope above a bench at the top of the Supai that corresponds to the Esplanade. Undoubtedly they are the Hermit shale. In this region the Coconino sandstone, although it is nearly 450 feet thick, does not make a cliff but weathers into a slope that is little steeper than that formed by the Hermit shale. The actual cliff-makers in the Aubrey cliff are the Supai formation and the Kaibab limestone.

Describing the beds in the Jerome region that were believed to represent the Supai, Ransome[53] writes:

> At this locality [mouth of Sycamore Creek, 8 miles north of Jerome] the lower 700 feet of the Supai consists chiefly of fine-grained cross-bedded sandstone in beds less than 6 feet thick, with a smaller proportion of deep-red shale. The general color is not brilliant, and some of the sandstone beds incline to a tawny hue. The upper beds of this division of the formation are fairly massive and form an outer bench in the plateau escarpment at this locality. Overlying them and under the Coconino sandstone are apparently softer beds of much brighter red, with an estimated thickness of 200 to 300 feet. As seen through field glasses at a distance of 2 or 3 miles they show conspicuous cross-bedding and appear to grade upward with no sharp break into the Coconino sandstone.

Perhaps the soft beds noted by Ransome beneath the Coconino sandstone and the rock bench formed by the Supai are the Hermit shale.

Fossils.—Schuchert was the first geologist to find fossils in the Hermit shale. He states:[54]

> Just below the sign "Red Top" in the lower turn of the Hermit trail [in Hermit Basin] and immediately above the thick upper sandstone [of the Supai] are seen thin. bedded red shaly sandstones alternating with deep-red zones of shale. The surfaces of the glistening and smooth platy sandstones are replete with fillings of the small prisms of interbedded sun-cracked shales, are often rain-pitted, and further marked by the feet impressions of fresh-water amphibians described elsewhere in this number of the Journal by Prof. Lull[55] as *Megapezia? coloradensis* and *Exocampe? delicatula*. Some of the tracks are distinct impressions of the feet, and others are mere strokes of the toes. In these same beds also occur plant remains in very fragmentary condition which were badly macerated and coated with a slime of red mud during their entombment. They are therefore difficult to determine, but after much effort Dr. David White tentatively identified them as *Callipteris* sp. cf. *C. conferta*, *Walchia* cf. *W. gracilis*, *Gigantopteris*, and cf. *Sphenophyllum*. * * *
>
> The plants listed above and found associated with the tracks led White in his letter to the writer dated June 27, 1916, to the following conclusions: "The condition of preservation of the fragments is so bad that caution is

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[51] Noble, L. F., op. cit., p. 70.

[52] Gilbert, G. K., op. cit., p. 162.

[53] Ransome, F. L., op. cit., p. 162.

[54] Schuchert, Charles, op. cit., pp. 353–354.

[55] Lull, R. S., Fossil footprints from the Grand Canyon of the Colorado: Jour. Am. Sci., vol. 45, pp. 337–346, May, 1918.

necessary in basing conclusions of any kind on the material submitted. However, the presence of *Gigantopteris*, *Walchia*, and probably of *Callipteris*, if my tentative generic identification of the latter is correct, points to lower Permian age of the flora. * * * In any event, it appears probable that the flora, when it is better known, will be found to indicate a level not below the highest stage of the Pennsylvanian."

In 1916 I made a small collection of plant material from beds at the base of the Hermit shale resting in depressions in the unconformity near Red Top in Hermit Basin. The collection was examined by Mr. White, who made the following report:

> The fossils are very obscure on account of the maceration of the plant substance, the washing of the surface with mud slimes, with more or less curling, and deformation produced apparently by shrinkage in the sun, so that the nervation is in general obliterated, even the midribs being imperfectly represented in some cases. Curling of the leaves obscures or even conceals their true forms.
>
> One of the specimens probably belongs to the genus *Pecopteris*. Two other fragments may represent a species of *Alethopteris*. Another fragment has the outline of *Callipteris*. If the outline is not misleading as the result of shrinkage and curling of the borders of the leaf, the plant probably is a *Callipteris*, in which case the evidence of the fossils will conform to the tentative age determinations based upon the collection submitted by Prof. Schuchert, namely, that the beds are Permian in age, or possibly referable to the latest Pennsylvanian.
>
> Pending the collection of additional material, some of which it is hoped will be found better preserved, the reference of the extremely obscure and imperfect fragments to the Permian must be considered as provisional. I anticipate, however, that more material will point more strongly to the Permian age of the upper part of the Supai formation. Should this prove to be the case, the unconformity at the base of the Permian in northern Arizona will remind geologists of the strong angular conformity beneath the Permian "Red Beds" on the south flank of the Ouachita Mountains in southern Oklahoma and the presence of inconspicuous conglomerate in or near the base of the Permian in northern Oklahoma and southern Kansas.

In 1920 I returned to Hermit Basin and searched the Hermit shale in the hope of getting material that would prove to be specifically determinable, and at a point 50 feet above the base of the formation, a quarter of a mile west of Red Top on the trail to Dripping Spring, at the locality shown in the sketch and photograph (fig. 4, *a*, and Pl. XXIV, *A*), I obtained among other specimens a well-preserved part of a fernlike frond, concerning which Mr. White writes:[56]

> A close inspection shows it to belong to the genus *Callipteris*, which the world over is everywhere recognized as the most characteristic and widespread exclusively Permian fern. I judge that the specimen is not even varietally distinguishable from *Callipteris conferta*. Accordingly this evidence practically confirms conclusively the opinions based on fragments previously collected by you and Prof. Schuchert and is of itself probably adequate to prove the Permian age of the Hermit shale. Taken in connection with the plant fragments previously transmitted by Prof. Schuchert and you, it can be only Permian.

In 1920 I noted imperfect fragments of plant impressions here and there in the Hermit shale near the Bass trail and near the Bright Angel trail. The fragments are not confined to any particular bed in the formation but occur at various horizons. They are not nearly so abundant as they are at Hermit Basin.

In the light of the evidence just presented the Hermit shale may be confidently assigned to the Permian.

COCONINO SANDSTONE.

Character.—The Coconino sandstone is a pale-buff fine-grained cross-bedded sandstone whose distinctive features are its massive appearance, the huge scale of the cross-bedding, and the uniform fineness of the component grains of sand. The massiveness of the sandstone, which is due to the coarseness of the cross-bedding, causes it to weather into the highest and most precipitous cliff in the upper wall of the canyon.

The formation is made up of lenticular beds, each of which is truncated by the bed above it in such a way that, as outlined in cross section or cliff faces, the beds commonly form irregular wedges whose sides are sweeping curves. Each wedge consists of innumerable thin inclined laminae. Horizontal bedding is absent except near the base of the formation, where it is inconspicuous. The wedges differ greatly in thickness. One wedge, near the Bass trail, is more than 75 feet thick; most are between 10 and 75 feet; some are less than 10 feet. In every wedge the laminae dip in a general southerly direction ranging from southeast to southwest, but the dip is not uniform in all parts of the wedge. The laminae form parallel curves that flatten downward. Commonly at the top of a wedge they are inclined at angles of 15° to 25°, or exceptionally 30°, but near the base of a wedge they bend and become horizontal or nearly horizontal. The prevailing dip of the laminae is south wherever the Coconino sandstone is exposed in northern thus almost double the height of the cliff as seen from the head of the Hermit trail or from Bass Camp.

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[56] White, David, personal letter.

Fossils.—The only traces of life that have been found in the Coconino sandstone are fossil footprints of small animals. The locality is on the Hermit trail between 140 and 200 feet above the base of the sandstone and is easily accessible. The tracks occur on the upper surfaces of inclined laminae of the sandstone that dip 15°–25° SW., and they are found over a considerable area between the elevations stated. The beds that contain the tracks have a slightly darker color than most of the Coconino sandstone exposed on the trail, weathering a rusty buff. The tracks are hard to recognize at first, as they are small, like those of a squirrel or a small cat, and the impressions are faint, but the tracks are abundant, and the observer will see a great many of them after he has become familiar with their appearance. Most of them appear to have been made by animals walking up the slope of the inclined laminae. A large number will be found in place on the outcropping inclined surfaces of the sandstone, but many loose slabs of rock scattered about the trail contain good impressions. The photograph reproduced in Plate XXV, *A*, shows impressions on one of these slabs. Specimens of two kinds of tracks collected by Prof. Schuchert in 1915 and by me in 1916 have been described by Lull [58] as *Laoporus schucherti* and *Laoporus noblei*. He regards the animals that made them as ancestral amphibia. He states:

> The creatures which made the footprints were quadrupeds of moderate size, with broad, stumpy feet, apparently clawed, and having at least four toes in front and five behind. The hind foot, which is somewhat the larger, bore a proportionately greater share of the creature's weight, especially in the smaller species. The limbs were apparently short, with a wide trackway, implying a bulky body. No trace of a dragging trail is discernible on any of the specimens, and the body was evidently carried clear of the ground. Several known genera of Paleozoic footprints may be compared with the present species, but none agrees with sufficient closeness to warrant the inclusion of these forms. They therefore seem to pertain to a new genus, which will be called *Laoporus* and the affinities of which, from the criteria which they present, seem to lie with the genus *Limnopus* Marsh, from the Kansas Coal Measures.

Probably the specimens described do not represent all kinds of tracks obtainable at this locality, for in examining the locality more carefully in 1920 I noted tracks that differ from those already described.

In origin I believe the Coconino sandstone is essentially a dune deposit, because it resembles in many structural and lithologic features parts of younger formations exposed in the Navajo country, notably the DeChelly, Navajo, and Wingate sandstones, which, as Gregory [59] has shown, are almost certainly dune deposits. Thin sections cut from specimens of the Coconino sandstone that I have collected for study may throw more light on the origin of the sand. This material, however, which also includes thin sections cut from beds in other Paleozoic formations of the Grand Canyon, has not yet been studied, and I will reserve a discussion of it for another report.

KAIBAB LIMESTONE.

Character.—The Kaibab limestone forms the surface of Coconino and Kaibab plateaus, which border the Grand Canyon, and makes the first cliffs that drop away at the rim of the canyon. It is composed of limestone and sandstone and at some horizons contains large amounts of chert. Fragments of chert weathered from the formation are abundant nearly everywhere on the surface of the plateaus. The beds of limestone are hard and make cliffs in the canyon wall; the sandstones are soft and make slopes. Relatively the Kaibab is not a heavily bedded formation, like the Redwall. Some limestone beds are over 6 feet thick, but many are from a few inches to 5 feet thick. The bedding planes are distinct throughout the formation. The prevailing colors of the limestones and of most of the sandstones are buff, cream, or gray, but some of the sandstones, notably in the middle part of the formation, are red or yellow. The limestones in the upper part of the formation are the most fossiliferous rocks in the Grand Canyon, some beds being composed almost entirely of the remains of sea animals, chiefly bryozoans, sponges, brachiopods, and gastropods. Fossil Mountain, a dissected promontory of the Coconino Plateau near Bass Camp, is carved from these fossiliferous beds and is so named because the fossils, weathered from the limestone, litter its southwest slope.

At Bass Canyon the Kaibab limestone is divisible into three members which in lithology and in topographic expression are distinct from one another everywhere in the Kaibab division. Subdivision A, at the top of the formation, 292 feet thick, consists of gray crystalline limestone which passes at the base and top into alternating beds of fine-grained sandstone and very cherty limestone. Subdivision B, in the middle of the formation, 136 feet thick, consists of more or less irregularly bedded buff, yellow, and red fine-grained sandstone and contains beds of sandy breccia. Subdivision C, at the base of the formation, 134 feet thick, consists of alternating beds of buff sandstone and limestone which pass up into a very massive bed of siliceous limestone. Subdivision A forms cliffs and steep slopes, B forms a slope, and C forms a succession of cliffs and slopes. The order, character, and succession of the beds that constitute these subdivisions are described in the section on pages 27–28, and the profile of the subdivisions is shown in the columnar section, Plate XIX.

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[58] Lull, R. S., op. cit., pp. 338–341.

[59] Gregory, H. E., Geology of the Navajo country: U. S. Geol. Survey Prof. Paper 93, pp. 31–34, 53–55, 57–59, 1917.

Two analyses of limestone in subdivision A follow. One analysis shows the composition of a sample taken from a bed (No. 2, p. 27) just under the rim of the canyon at the Bass trail. This limestone is associated with the sandy beds in the upper part of the subdivision. It is dense but not crystalline, feels dull or earthy when struck by the hammer, and in appearance suggests silicified chalk. Similar beds higher in the Kaibab limestone are exposed on the Coconino Plateau east of Bass Camp but are not included in my section.

This rock is an impure dolomite. The second analysis shows the composition of the limestone that forms the greater part of the subdivision. This limestone is hard, gray, more or less cherty, very fossiliferous, and entirely crystalline. The sample analyzed was taken from bed No. 6 at the Bass trail. (See p. 27.) The analysis shows that this limestone is not magnesian, although it is relatively impure. Probably the insoluble impurities are largely the silica that forms nodules of chert associated with the limestone, for the rock represented by the sample analyzed contains no detrital sand.

Partial chemical analyses of limestone from subdivision A, Kaibab limestone.

[Alfred A. Chambers, analyst.]

	1	2
Insoluble	6.98	11.15
$(Al, Fe)_2O_3$	.56	.71
CaO	29.98	48.68
MgO	18.68	.00

The sandstones of subdivision B consist entirely of quartzose sand which in composition, fineness, and uniformity of grain resembles the sand in the Coconino sandstone. Much of the sandstone is loosely consolidated and crumbles to sand when struck with the hammer. The cement appears to be siliceous, for the rock does not effervesce with acid. Some beds are evenly laminated; others exhibit curious gnarly structure like that in parts of the Devonian Temple Butte limestone (p. 51). Wavy, irregular surfaces separate many beds. A bed of brecciated sandstone occurs at the top of the subdivision at Bass Canyon, and a similar bed occurs near the middle. (See p. 27.) It is difficult to determine from the exposures at this locality whether the brecciated structure is detrital in origin, the fragments representing boulders in a conglomerate, or whether the structure was acquired after the beds were consolidated, the beds caving in and breaking because some soluble mineral, perhaps gypsum, was leached out of them. The sandstones of the subdivision contain no gypsum at the Bass trail, but equivalent beds at Kanab Creek described by Walcott (see Pl. XIX) contain gypsum, as also do equivalent beds at Cataract Creek described by Newberry.[60] Cataract Creek is about 20 miles southwest of Bass Canyon.

The prevailing reddish and yellowish hues of the sandstones that constitute subdivision B contrast strikingly with the pale buffs and grays of the strata in the overlying and underlying subdivisions of the Kaibab and enable the observer readily to distinguish the subdivision.

In general appearance the limestone in the massive cliff-making bed at the top of subdivision C (see p. 28) resembles that in the bed at the top of subdivision A, whose composition is shown by the analysis on this page to be near that of dolomite. Probably the rock is a siliceous dolomitic limestone. The sandstones that alternate with the limestones below this bed do not appear to differ conspicuously in composition from those in subdivision B, but all of them are evenly bedded, and some exhibit shaly lamination. The contact between subdivision C and the underlying Coconino sandstone is level and even, and the bottom bed of the subdivision,

a fine-grained reddish to yellowish sandstone, rests everywhere on the truncated edges of inclined laminae of the Coconino sandstone.

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[60] Newberry, J. S., Report upon the Colorado River of the West, explored in 1857-58 by Lieut. J. C. Ives, pt. 3, Geological report, 1861.

Thickness.—The Kaibab limestone is 562 feet thick at the Bass trail and about 25 feet thicker a short distance east of the trail, but inasmuch as the summit of the formation is the eroded surface of the Coconino Plateau, the original thickness can not be determined. In fact, the only place where it can be determined in the Kaibab division is in the area between the rim of the Grand Canyon and Cedar Mountain, 35 miles southeast of Bass Canyon. At Cedar Mountain, 2 miles from the rim of the canyon, the Kaibab is overlain by younger beds that have not been removed by erosion, and the top of the Kaibab is exposed beneath these beds at the southern base of the mountain. As shown on page 72 certain beds at the top of the Kaibab at the base of the mountain can be identified with beds exposed at the top of the Kaibab at the rim of the canyon 2 miles away. Therefore the original thickness of the Kaibab can be obtained by measuring the formation in the canyon wall at this point and adding the thickness of Kaibab beds exposed under Cedar Mountain that have been removed at the rim of the canyon. These measurements have not been made.

Although the three subdivisions of the Kaibab limestone are everywhere readily distinguishable from one another they exhibit variations in thickness and lithology as they are traced southeastward through the Kaibab division from Bass Canyon. At Red Canyon, on the Hance trail, 30 miles southeast of Bass Canyon, subdivision C, at the base of the formation, is 75 feet thick, whereas at Bass Canyon it is 134 feet thick. The cliff-making bed of buff limestone at the top of the subdivision is about equally thick at both localities, but the alternating sandstones and limestones between this bed and the Coconino sandstone have shrunk from 86 feet at Bass Canyon to 30 feet at Red Canyon.

Subdivision B is 143 feet thick at Red Canyon, practically of the same thickness as at Bass Canyon, and the component beds of sandstone differ very little at the two localities. The subdivision contains brecciated sandstone at Red Canyon, as it does at Bass Canyon, but at Red Canyon the brecciated sandstone occupies a horizon near the middle of the subdivision, whereas at Bass Canyon it occurs at both the middle and the top. At Red Canyon the brecciated sandstone forms a bed 15 feet thick and consists of angular fragments of red and buff sandstone as much as 4 feet in diameter embedded in a matrix of gnarled and twisted sandstone. At this locality the brecciated sandstone appears to represent a conglomerate, not a bed shattered after deposition and consolidation. Undoubtedly these brecciated beds are a constant feature of subdivision B, for I have seen them at all localities where I have examined the subdivision between Bass Canyon and Red Canyon. One of these beds is exposed on the Hermit trail.

Subdivision A is 355 feet thick at Red Canyon and 292 feet thick at Bass Canyon, but the summit is eroded at both places, so that the differences in thickness may not be significant. At Red Canyon, as at Bass Canyon, chert is less abundant in the middle of the subdivision than near the base and top and is most abundant near the top. The limestone in the subdivision at Red Canyon, however, is not nearly so pure as it is at Bass Canyon, is not prevailingly crystalline, and most beds are earthy, sandy, or siliceous, resembling the buff magnesian limestone at the top of the Bass Canyon section rather than the gray crystalline limestone that constitutes the greater part of the subdivision at Bass Canyon. Thus subdivision A as a whole becomes sandier and more siliceous southeastward from Bass Canyon. The limestones are decidedly more sandy at the Hermit trail than they are at the Bass trail and more sandy at Red Canyon than they are at the Hermit trail.

Fossils.—Fossils are very abundant at many horizons in subdivision A. At Bass Canyon they are most abundant in the beds of gray crystalline limestone designated 5 and 6 in my section (p. 27). The following list of a collection in the possession of G. H. Girty obtained at Parusi-Wompats Spring, just north of the Shinumo region, includes most of the forms that occur near Bass Canyon:[61]

Sponges.
Lophophyllum n. sp.
Crinoid stems.
Fistulipora sp.

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[61] Noble, L. F., op. cit., p. 71.

Meekopora sp.
Stenopora sp.
Septopora sp.
Polypora sp.
Lingulidiscina convexa?
Derbya sp.
Meekella pyramidalis.
Chonetes aff. C. hillianus.
Producus occidentalis.
Productus ivesii.
Productus aff. P. irginae.
Productus subhorridus var. rugatulus.
Productus sp.
Pugnax osagensis var.
Heterelasma n. sp.
Squamularia guadalupensis?
Spiriferina campestris?
Composita subtilita.
Aviculipecten, 2 sp.
Acanthopecten occidentalis.
Pseudomonotis aff. P. hawni.
Pseudomonotis? sp.
Anisopyge perannulata?

These and other fossils constitute the so-called *Productus ivesii* fauna. Girty regards this fauna as Permian and tentatively correlates the Kaibab limestone with the San Andres limestone in the Manzano group of New Mexico.

No fossils have been found in subdivision B, the sandstone member of the Kaibab, but a few occur in subdivision C. So far as I know, no fossils have been collected and described from these two lower subdivisions of the Kaibab limestone in the Grand Canyon, and it is therefore conceivable that the lower part of the formation may contain a fauna differing somewhat from that in the upper part. However, Newberry's section at Cataract Creek[62] mentions *Productus ivesii* in beds equivalent to those at the base of subdivision C. Inasmuch as the Hermit shale beneath the Kaibab contains Permian plant remains, no part of the Kaibab can be older than Permian.

BEDS OVERLYING THE KAIBAB LIMESTONE AT CEDAR MOUNTAIN.

No beds younger than the Kaibab limestone are exposed in the wall of the Grand Canyon in the Kaibab division, but Cedar Mountain, a flat-topped butte on the Coconino Plateau only 2 miles east of the rim of the canyon near Desert View Camp, is carved from younger beds. These beds at Cedar Mountain constitute two formations—the Shinarump conglomerate, 25 feet thick, which makes a cliff encircling the top of the mountain and determines its flat summit, and the Moenkopi formation, 481 feet thick, which makes the slopes of the mountain. The age of these two formations is Mesozoic, the Moenkopi being regarded as Lower Triassic and the Shinarump as probably Upper Triassic. The Moenkopi formation, which is relatively soft, owes its preservation to the hard Shinarump conglomerate that caps it. Cedar Mountain is accessible by a rather poor road or may be reached by walking 3 or 4 miles across country from Desert View Camp, which is connected with El Tovar by a good road. It is interesting not only because it affords evidence that the Moenkopi and Shinarump formations once covered the Grand Canyon region, but because the Shinarump conglomerate, which caps it, contains petrified wood. Plate XXV, *B*, shows Cedar Mountain as seen from Desert View Camp.

Inasmuch as the formations in Cedar Mountain are exposed within 2 miles of the rim of the Grand Canyon they may be considered a part of the Grand Canyon stratigraphic section, and I have therefore included a section of them in the present report. This section, which follows, is probably inaccurate in detail, because I obtained the thicknesses of the beds by rough aneroid measurement and because the exposures of many beds are poor owing to the apron of débris that cloaks the slopes of the mountain. However, the section serves to give a general idea of the character and succession of the beds.

Section of beds exposed on south side of Cedar Mountain, Vishnu quadrangle.

	Feet.
Shinarump conglomerate (Upper? Triassic): Hard siliceous conglomerate or pebbly grit composed chiefly of pebbles of quartz or jasper embedded in a matrix of quartzose sand: caps Cedar Mountain and forms strong cliff. Cross-bedded throughout; texture variable, some beds fine grained, others coarse grained. Rounded pebbles of white quartz a quarter of an inch to an inch in diameter predominate in the coarser beds; the jasper pebbles are of different colors and are banded and variegated: probably the jasper is petrified wood. Several logs of petrified wood are embedded in the conglomerate. The constituent pebbles of the conglomerate are unidentifiable with any rock in the underlying Moenkopi...........	25

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[62] Newberry, J. S., op. cit.

a fine-grained reddish to yellowish sandstone, rests everywhere on the truncated edges of inclined laminae of the Coconino sandstone.

Thickness.—The Kaibab limestone is 562 feet thick at the Bass trail and about 25 feet thicker a short distance east of the trail, but inasmuch as the summit of the formation is the eroded surface of the Coconino Plateau, the original thickness can not be determined. In fact, the only place where it can be determined in the Kaibab division is in the area between the rim of the Grand Canyon and Cedar Mountain, 35 miles southeast of Bass Canyon. At Cedar Mountain, 2 miles from the rim of the canyon, the Kaibab is overlain by younger beds that have not been removed by erosion, and the top of the Kaibab is exposed beneath these beds at the southern base of the mountain. As shown on page 72 certain beds at the top of the Kaibab at the base of the mountain can be identified with beds exposed at the top of the Kaibab at the rim of the canyon 2 miles away. Therefore the original thickness of the Kaibab can be obtained by measuring the formation in the canyon wall at this point and adding the thickness of Kaibab beds exposed under Cedar Mountain that have been removed at the rim of the canyon. These measurements have not been made.

Although the three subdivisions of the Kaibab limestone are everywhere readily distinguishable from one another they exhibit variations in thickness and lithology as they are traced southeastward through the Kaibab division from Bass Canyon. At Red Canyon, on the Hance trail, 30 miles southeast of Bass Canyon, subdivision C, at the base of the formation, is 75 feet thick, whereas at Bass Canyon it is 134 feet thick. The cliff-making bed of buff limestone at the top of the subdivision is about equally thick at both localities, but the alternating sandstones and limestones between this bed and the Coconino sandstone have shrunk from 86 feet at Bass Canyon to 30 feet at Red Canyon.

Subdivision B is 143 feet thick at Red Canyon, practically of the same thickness as at Bass Canyon, and the component beds of sandstone differ very little at the two localities. The subdivision contains brecciated sandstone at Red Canyon, as it does at Bass Canyon, but at Red Canyon the brecciated sandstone occupies a horizon near the middle of the subdivision, whereas at Bass Canyon it occurs at both the middle and the top. At Red Canyon the brecciated sandstone forms a bed 15 feet thick and consists of angular fragments of red and buff sandstone as much as 4 feet in diameter embedded in a matrix of gnarled and twisted sandstone. At this locality the brecciated sandstone appears to represent a conglomerate, not a bed shattered after deposition and consolidation. Undoubtedly these brecciated beds are a constant feature of subdivision B, for I have seen them at all localities where I have examined the subdivision between Bass Canyon and Red Canyon. One of these beds is exposed on the Hermit trail.

Subdivision A is 355 feet thick at Red Canyon and 292 feet thick at Bass Canyon, but the summit is eroded at both places, so that the differences in thickness may not be significant. At Red Canyon, as at Bass Canyon, chert is less abundant in the middle of the subdivision than near the base and top and is most abundant near the top. The limestone in the subdivision at Red Canyon, however, is not nearly so pure as it is at Bass Canyon, is not prevailingly crystalline, and most beds are earthy, sandy, or siliceous, resembling the buff magnesian limestone at the top of the Bass Canyon section rather than the gray crystalline limestone that constitutes the greater part of the subdivision at Bass Canyon. Thus subdivision A as a whole becomes sandier and more siliceous southeastward from Bass Canyon. The limestones are decidedly more sandy at the Hermit trail than they are at the Bass trail and more sandy at Red Canyon than they are at the Hermit trail.

Fossils.—Fossils are very abundant at many horizons in subdivision A. At Bass Canyon they are most abundant in the beds of gray crystalline limestone designated 5 and 6 in my section (p. 27). The following list of a collection in the possession of G. H. Girty obtained at Parusi-Wompats Spring, just north of the Shinumo region, includes most of the forms that occur near Bass Canyon:[18]

Sponges.
Lophophyllum n. sp.
Crinoid stems.
Fistulipora sp.

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[18] Noble, L. F., op. cit., p. 71.

a fine-grained reddish to yellowish sandstone, rests everywhere on the truncated edges of inclined laminae of the Coconino sandstone.

Thickness.—The Kaibab limestone is 562 feet thick at the Bass trail and about 25 feet thicker a short distance east of the trail, but inasmuch as the summit of the formation is the eroded surface of the Coconino Plateau, the original thickness can not be determined. In fact, the only place where it can be determined in the Kaibab division is in the area between the rim of the Grand Canyon and Cedar Mountain, 35 miles southeast of Bass Canyon. At Cedar Mountain, 2 miles from the rim of the canyon, the Kaibab is overlain by younger beds that have not been removed by erosion, and the top of the Kaibab is exposed beneath these beds at the southern base of the mountain. As shown on page 72 certain beds at the top of the Kaibab at the base of the mountain can be identified with beds exposed at the top of the Kaibab at the rim of the canyon 2 miles away. Therefore the original thickness of the Kaibab can be obtained by measuring the formation in the canyon wall at this point and adding the thickness of Kaibab beds exposed under Cedar Mountain that have been removed at the rim of the canyon. These measurements have not been made.

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Subdivision B is 143 feet thick at Red Canyon, practically of the same thickness as at Bass Canyon, and the component beds of sandstone differ very little at the two localities. The subdivision contains brecciated sandstone at Red Canyon, as it does at Bass Canyon, but at Red Canyon the brecciated sandstone occupies a horizon near the middle of the subdivision, whereas at Bass Canyon it occurs at both the middle and the top. At Red Canyon the brecciated sandstone forms a bed 15 feet thick and consists of angular fragments of red and buff sandstone as much as 4 feet in diameter embedded in a matrix of gnarled and twisted sandstone. At this locality the brecciated sandstone appears to represent a conglomerate, not a bed shattered after deposition and consolidation. Undoubtedly these brecciated beds are a constant feature of subdivision B, for I have seen them at all localities where I have examined the subdivision between Bass Canyon and Red Canyon. One of these beds is exposed on the Hermit trail.

Subdivision A is 355 feet thick at Red Canyon and 292 feet thick at Bass Canyon, but the summit is eroded at both places, so that the differences in thickness may not be significant. At Red Canyon, as at Bass Canyon, chert is less abundant in the middle of the subdivision than near the base and top and is most abundant near the top. The limestone in the subdivision at Red Canyon, however, is not nearly so pure as it is at Bass Canyon, is not prevailingly crystalline, and most beds are earthy, sandy, or siliceous, resembling the buff magnesian limestone at the top of the Bass Canyon section rather than the gray crystalline limestone that constitutes the greater part of the subdivision at Bass Canyon. Thus subdivision A as a whole becomes sandier and more siliceous southeastward from Bass Canyon. The limestones are decidedly more sandy at the Hermit trail than they are at the Bass trail and more sandy at Red Canyon than they are at the Hermit trail.

Fossils.—Fossils are very abundant at many horizons in subdivision A. At Bass Canyon they are most abundant in the beds of gray crystalline limestone designated 5 and 6 in my section (p. 27). The following list of a collection in the possession of G. H. Girty obtained at Parusi-Wompats Spring, just north of the Shinumo region, includes most of the forms that occur near Bass Canyon:[a]

Sponges.
Lophophyllum n. sp.
Crinoid stems.
Fistulipora sp.

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[a] Noble, L. F., op. cit., p. 71.

	Feet.
Unconformity (?). The contact between the Shinarump conglomerate and the underlying shale is concealed nearly everywhere by talus. The only exposure noted, a few feet in horizontal extent, shows conglomerate resting on reddish-brown sandy shale; lithologic change from shale to conglomerate very sharp.	
Moenkopi formation (Lower Triassic):	
1. Slope; practically all covered by débris. The few outcrops consist of thinly laminated reddish-brown shale or shaly sandstone	60
2. Strong cliff; very massive reddish-brown fine-grained, strongly cross-bedded sandstone	80
3. Slope; soft, thinly laminated tan to reddish-brown sandy shale. Outcrops covered with white saline efflorescence, indicating the presence of much saline material in the rock	130
4. Weak cliff; rather massive buff sandstone exhibiting indistinct cross-bedding	16
5. Slope; thinly laminated tan sandstone or sandy shale	5
6. Cliff; light yellowish-buff to creamy-buff fine-grained rather massive cross-bedded sandstone	18
7. Long, gentle slope almost entirely covered by talus. The few outcrops are mostly thinly laminated soft brownish or reddish shale. The upper part of this member, just under the overlying buff sandstone, is bright-vermilion shale; the basal portion is slabby fine-grained thin-bedded sandstone which exhibits lemon and tan tints and is markedly calcareous	150
8. Tiny cliff; greenish-buff, thinly laminated crystalline limestone, somewhat sandy in places	1
9. Slope; platy, very thinly laminated greenish and brownish-buff calcareous shaly sandstone, passing up into brownish-buff and vermilion beds of the same character	15
10. Curious gnarly cherty bed. In places a conglomerate of angular chert fragments; in places a massive gnarly sandy chert. Thickness variable	0–4
11. Massive yellowish-buff fine-grained sandstone. Thickness variable	0–2
	481
Unconformity (?). The irregularity of the beds at this horizon and the presence in them of brecciated chert indicate a surface of erosion, but the outcrops are not of sufficient extent to afford conclusive evidence.	
Kaibab limestone (Permian):	
1. Massive buff sandstone containing lenses of chert and many casts of fossils; casts of *Productus?* are the most abundant. Thickness of bed variable and its surface appears wavy	2–6
2. Partly concealed bed, making slope. Apparently consists of alternating thin layers of chert and lemon-buff sandstone	5
3. Cliff; massive gray to buff sandstone; calcareous; contains casts of *Productus?*	7
4. Not measured. Thin layers of rubbly chert and fine-grained lemon-buff to pinkish-buff sandstone. Thickness at least 40 feet. The beds forming this cherty series are plainly equivalent to similar cherty beds in the Kaibab limestone that are exposed in the wall of the Grand Canyon just under the rim at Desert View, 3 miles away.	

The section just given may be compared with Gregory's type section of the Moenkopi formation for the Little Colorado Valley, measured 5 miles below Tanner Crossing, in the wall of the valley.[63] Tanner Crossing is about 20 miles southeast of Cedar Mountain. Both sections include the entire Moenkopi, with the Shinarump conglomerate exposed above it and the top of the Kaibab limestone exposed below. Gregory's section of the Moenkopi is 389 feet thick, whereas the section at Cedar Mountain above the Kaibab limestone measures 481 feet. The Cedar Mountain section differs from Gregory's section chiefly in that it contains massive beds of cross-bedded sandstone in the upper part, and it is conceivable that this massive sandstone at Cedar Mountain represents the De Chelly sandstone of the Navajo country, which, as Gregory has shown, is sporadic in occurrence and occupies a stratigraphic position between the Moenkopi formation and the Shinarump conglomerate. However, great and sudden variability in lithology both vertically and horizontally is a normal feature of the Moenkopi, as Gregory has pointed out. Moreover, cross-bedded sandstone is not uncommon in the Moenkopi, so that its presence at Cedar Mountain is not necessarily significant. Unconformities between the Shinarump and Moenkopi and between the Moenkopi and Kaibab can not be determined by conclusive evidence at Cedar Mountain, because the exposures of the contacts between the formations are of small extent, but inasmuch as Gregory has shown conclusively that these unconformities exist in the general region and are widespread, it is highly probable that the features I have described as occuring at the contacts between the formations at Cedar Mountain indicate their presence.

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[63] Gregory, H. E., op. cit., p. 24.

I obtained no fossils in the Moenkopi at Cedar Mountain, but fossils collected in it by Longwell [64] in Nevada and determined by Girty show that its age is Lower Triassic. Therefore the probable unconformity between the Moenkopi formation and the Kaibab limestone separates deposits of the Paleozoic and Mesozoic eras.

Gregory [65] has tentatively assigned the Shinarump conglomerate to the Upper Triassic.

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[64] Longwell, C. R., op. cit., p. 50.

[65] Gregory, H. E., op. cit., p. 41.

THE SHAPES OF BEACH PEBBLES.

By Chester K. Wentworth.

PURPOSE OF THE STUDY.

There is much confusion in geologic literature as to the shapes of fluvial and beach pebbles and the differences between them, if differences exist. Though the contrary has been asserted, most geologists who have written on the subject appear to hold the view that beach pebbles are generally flatter than river pebbles, having discoid, lozenge-shaped, ellipsoid, or oval forms.[1] It is asserted by some that these forms are produced by pushing of the rock fragments to and fro by the waves.[2] Others have considered that the shapes of the original fragments and the inherent structure of the rock are dominant in determining the shapes of beach pebbles,[3] and with this view the writer is in accord. That beach pebbles, even those composed of massive igneous rocks, are commonly of a flattened oval form seems certain, as has been stated elsewhere,[4] but this fact is probably to be attributed to the development of such forms from original flat fragments or from rocks of schistose structure or to the segregation of such forms under the peculiar action of the waves, rather than to their production by a specialized wave abrasion.

Though many opinions on the subject have been expressed, no one, so far as known to the writer, has made any quantitative test of the development of such shapes on a beach. It was the writer's good fortune during the summer of 1921 to visit two localities on the Atlantic coast of New England where pebbles are being produced by wave abrasion of igneous rock in place. At these localities he measured more than 300 pebbles with the hope of obtaining evidence that would be conclusive, at least so far as these localities are concerned. The results obtained are presented on the following pages. It is the writer's hope that geologists acquainted with localities where similar measurements might be made or where conditions of wave abrasion are especially effective or peculiar will refer him to such places.

BEACH CONDITIONS.

The first locality visited was at the south extremity of Nantasket Beach, at the point shown on the topographic map of the Boston Bay quadrangle under the capital A of "Atlantic." Here, on the east side of the point, is a beach about 200 feet in length which is composed of material ranging from sand to blocks and boulders a foot or more in diameter. At each end the beach is terminated by low promontories of the local light-green to gray igneous rock, which is included in the Mattapan volcanic complex as mapped by Emerson.[5] The greater part of the gravel of the beach is derived from the adjacent outcrops, which show, however, great variations in type within short distances, including some pyroclastic and sedimentary derivatives of the igneous rock. In addition to the local rock there is a considerable admixture of pebbles of granite, porphyry, breccia, felsite, and many other kinds of igneous rock from other parts of eastern Massachusetts which have been transported by glacial ice, by streams, and by shore currents. The general character of the beach gravel is shown in Plate XXVI. The conditions of abrasion at this point are those of a pocket beach. The tides rise and fall, shifting the zone of abrasion by several feet in height and about 75 to 100 feet horizontally. Storm waves break high over the north-south beach ridge and both adjacent rock promontories. Gravel is not transported to any extent from the beach, either alongshore or out to deep water, and remains indefinitely in the zone of effective abrasion. The coast at this place trends northwest, and the beach is exposed to the full force of waves from the northeast, but not so much to those from south of east.

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[1] Suess, E., Der Boden der Stadt Wien, pp. 64, 65, 1882 (quoted from Grabau, A. W., Principles of stratigraphy, p. 595, 1913).

Hoernes, R., Gerölle und Geschiebe: K. k. geol. Reichsanstalt Verh. No. 12, pp. 42 et seq., 1911 (quoted from Grabau, A. W., op. cit., p. 595).

Cole, G. A. J., Rocks and their origins, p. 71, Cambridge Univ. Press, 1912.

Trowbridge, A. C., Classification of common sediments: Jour. Geology, vol. 22, p. 435, 1914.

Stephenson, L. W., The Coastal Plain of North Carolina: North Carolina Geol. and Econ. Survey, vol. 3, pp. 274–275, 1912.

Geikie, A., Textbook of geology, vol. 1, p. 569, 1903.

[2] Suess, E., op. cit. Hoernes, R., op. cit. Cole, G. A. J., op. cit.

[3] Grabau, A. W., Principles of stratigraphy, pp. 715–716, 1913.

Dunn, E. J., Pebbles, p. 7, Sydney, G. Robertson & Co., 1911.

[4] Wentworth, C. K., Quantitative studies of the shapes of pebbles (unpublished thesis, Iowa State Univ.).

[5] Emerson, B. K., U. S. Geol. Survey Bull. 597, p. 200, 1917.

The site of the second series of measurements was the rocky shore at the entrance to New Haven Harbor, near Fort Hale, Conn. Here, for a distance of several hundred feet, is a wave-cut cliff and abrasion platform cut in the end of a north-south ridge of Triassic trap that reaches the shore. Along the cliff and strewn in both directions on the beach is considerable gravel composed of trap from the local exposure. This gravel extends only a few hundred feet in each direction, giving way to sand and finer materials. Mingled with the trap pebbles of the gravel are a few pebbles and larger pieces from the glacial till that overlies the bedrock at the top of the cliff and is exposed lower down along the adjacent parts of the shore. These are readily identified by inspection. The general character of the shore and gravel at this point is shown in Plate XXVII.

On this beach wave action is far less effective as an agent of abrasion than at Nantasket. Not only are the waves in this part of Long Island Sound less violent than those of the Atlantic Ocean at Nantasket, but the pebbles here are not confined in a pocket beach.

METHODS OF MEASUREMENT.

Three diameters mutually at right angles were measured for each pebble with a steel tape. The radius of curvature of the sharpest edge of each was measured with the convexity gage described elsewhere.[6] All measurements were in millimeters. The data were recorded in several groups as follows:

Nantasket:		Pebbles.
A. Random selection, all materials		61
B. Miscellaneous rock types:		
Quartzite	20	
Red porphyry	20	
Black porphyry	10	
Granite	10	
		60
C. Local volcanic rock		80
		201
Fort Hale:		
D. Local trap		101

LABORATORY DETERMINATIONS.

The relative resistance of the local rocks at the two beaches was determined by an abrasion test in the tumbling mill. Four pebbles of each rock were ground at one end on a lap to a sharp 90° edge. They were then subjected to abrasion in the mill for a total distance of about 80 miles. Measurements of the convexity of the prepared edge were made at intervals, and the resulting data were used in comparing the durability of the two types of rock.

COMPUTATIONS.

Computations were made as follows for each pebble:

Mean diameter,[7] computed approximately by the formula $D=\sqrt[3]{D'D''D'''}$ where D', D'', and D''' are the length, breadth, and thickness as measured in the field.

Roundness ratio, $\frac{r_1}{R}=\frac{2r_1}{D}$, where r_1 is the radius of curvature in millimeters of the sharpest edge and R is the mean radius of the pebble.

Flatness ratio, $\frac{D'+D''}{2D'''}$ or the average of the length and breadth divided by the thickness.

All these values were computed to two significant figures by the use of graphic charts. Further description of these ratios and methods of computation has been given elsewhere.[8]

RESULTS.

The results of the measurements are plotted on the graphs of figures 5 to 10. The variations of the roundness ratios are so great that for practical considerations it seems better to average these ratios by subgroups. These averages were made as described below, and the subgroups are indicated by the large dots in figure 5 and by all the dots in figures 6 to 10, where the number of pebbles represented by each dot is shown by the small accompanying figures. In the subgroups marked X under

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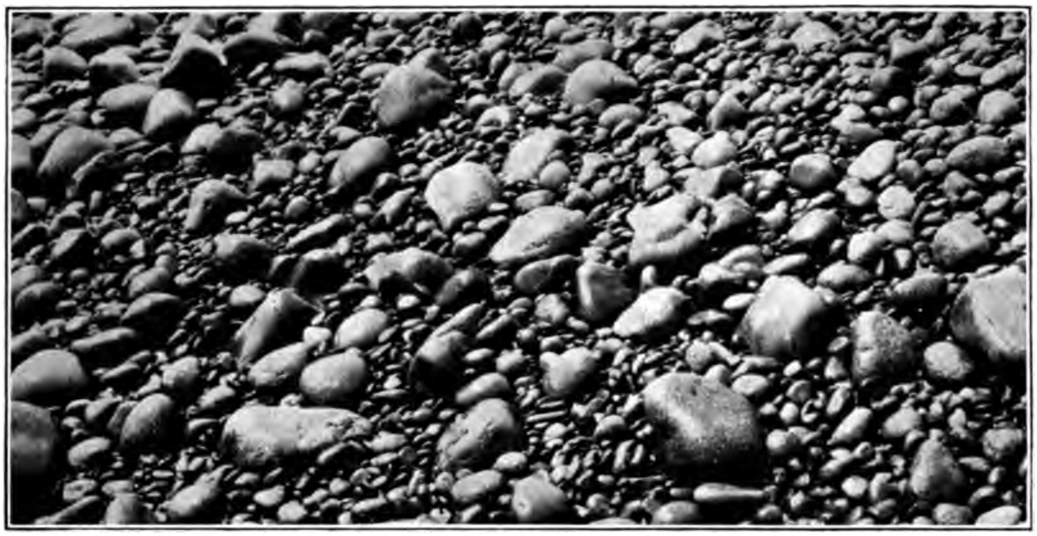
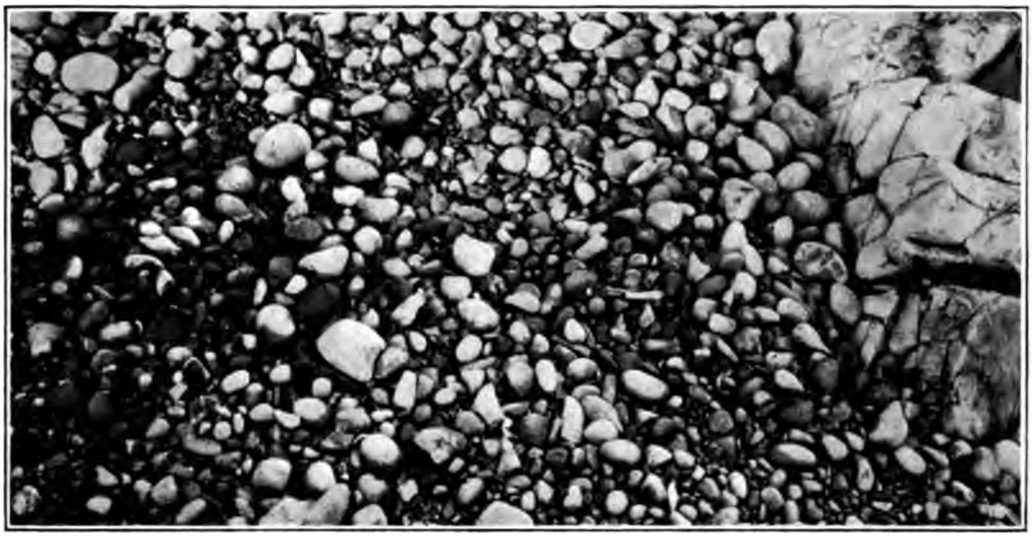
[6] Wentworth, C. K., Quantitative studies of the shapes of pebbles (unpublished thesis, Iowa State Univ.), p. 61, 1921. See also Wentworth, C. K., The shapes of pebbles: U. S. Geol. Survey Bull. 730, pp. 91-114, 1922.

[7] The writer's use of the term "mean diameter" is open to the objection that in the use of the approximate formula given above the true value of the arithmetic mean of all diameters (the ideal concept of the term) is not derived. The writer does not consider the objection to be serious, for it applies in varying degree to all physical constants that are based on empirical data. It is customary to speak of the values derived for these constants as the theoretical constants themselves, and the common practice seems not to be unduly confusing. Therefore, in the following pages where the term "mean diameter" is used, the actual numerical values are understood to be approximations to the true arithmetical mean of all diameters.

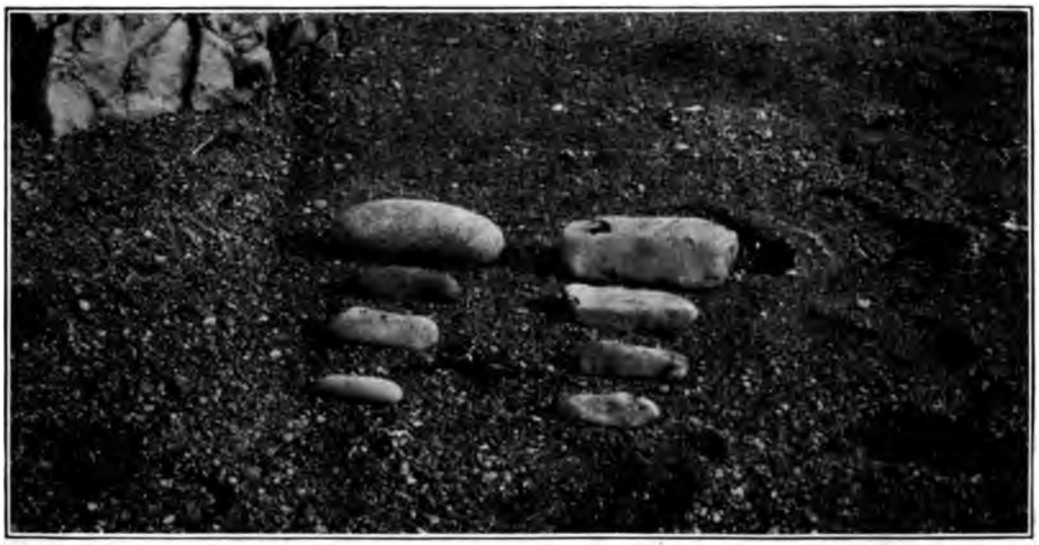
[8] Wentworth, C. K., The shapes of pebbles: U. S. Geol. Survey Bull. 730, pp. 91-114, 1922.



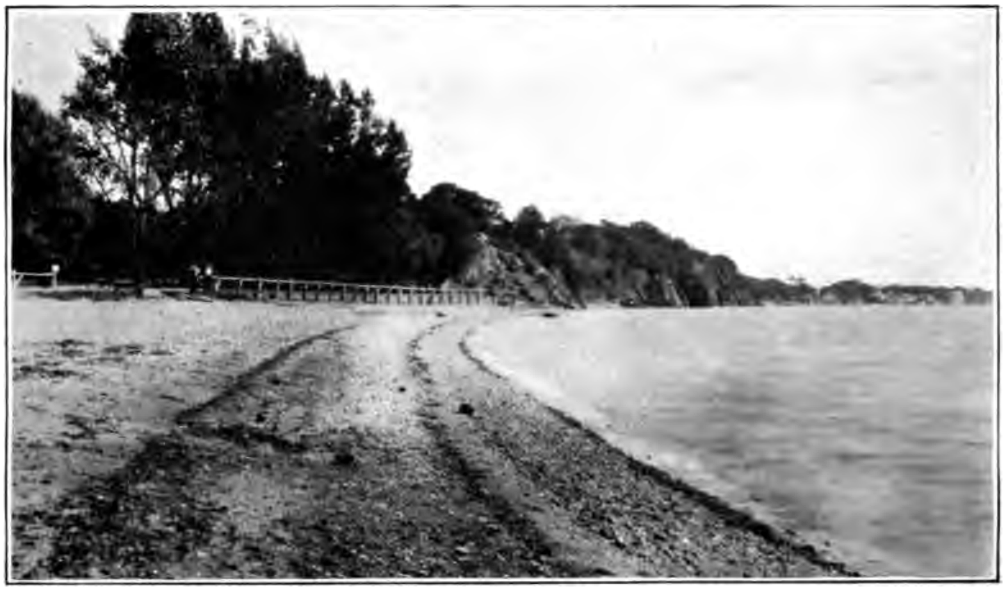
A. GRAVEL IN POCKET BEACH SOUTH OF NANTASKET, MASS.



B. GRAVEL AND JOINTED ROCK OF PROMONTORY SOUTH OF NANTASKET, MASS.

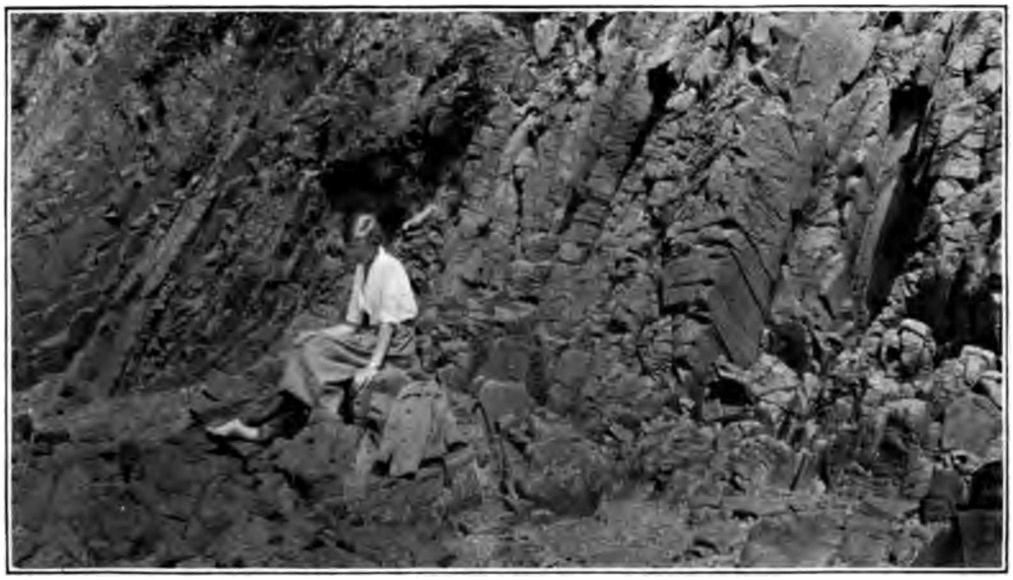


C. ROLLER-SHAPED COBBLES IN TWO STAGES OF FORMATION, POCKET BEACH SOUTH OF NANTASKET, MASS.



A. BEACH AT FORT HALE, CONN.

The cliff in the middle distance is the source of pebble material.



B. NEAR VIEW OF CLIFF OF JOINTED TRAP AND LANDWARD EDGE OF ABRASION PLATFORM AT FORT HALE, CONN.

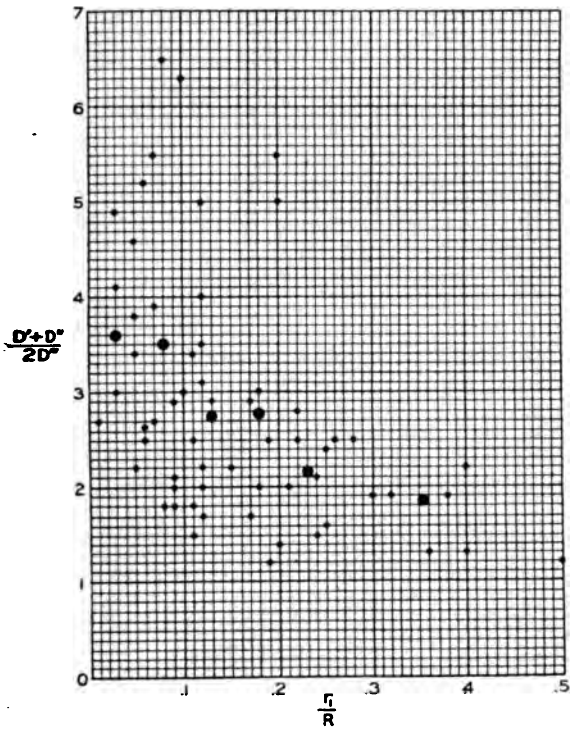


FIGURE 5.—Graph showing flatness ratios $\frac{D'+D''}{2D'''}$ (ordinate) and roundness ratios $\frac{r_1}{R}$ (abscissa) of 61 pebbles of group A at Nantasket, Mass. Large dots show average positions for subgroups of pebbles. (See fig. 6.)

"Method of computing averages" in the following table the values of $\frac{D'+D''}{2D'''}$ for all the pebbles of the subgroup were averaged arithmetically for the ordinate, and the mean of the limits of $\frac{r_1}{R}$ for the subgroup was used for abscissa. In the subgroups marked Y the values of $\frac{D'+D''}{2\,D'''}$ were averaged similarly for the ordinate and the values of $\frac{r_1}{R}$ for all the pebbles of the subgroup were averaged arithmetically for the abscissa. Method X was used for the subgroups in which values of $\frac{r_1}{R}$ were fairly uniformly and thickly distributed; method Y was used for subgroups in which a few erratic points needed to be averaged. The subgroup limits were chosen to avoid as far as possible very small subgroups or very great differences in the number of pebbles in adjacent subgroups. No data were rejected, and every measurement taken in the field is represented in the averages here presented.

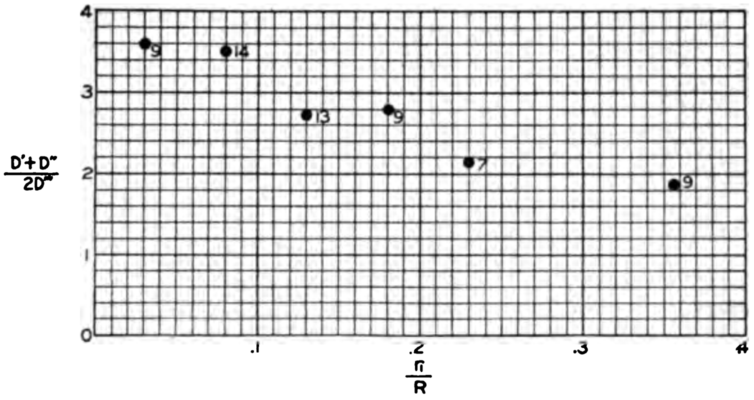


FIGURE 6.—Graph showing flatness and roundness of 61 pebbles of group A. The flatness ratio $\frac{D'+D''}{2\,D'''}$ is plotted as the ordinate and the roundness ratio $\frac{r_1}{R}$ as the abscissa. For simplicity, the pebbles are arranged in subgroups, and each large dot shows the mean position of the number of pebbles indicated by the small figures. It is apparent that as the roundness increases the flatness decreases.

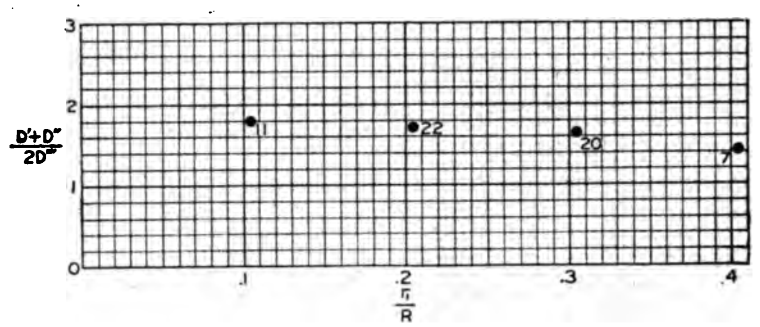


FIGURE 7.—Graph showing flatness and roundness ratios of pebbles of group B. For explanation, see figure 6.

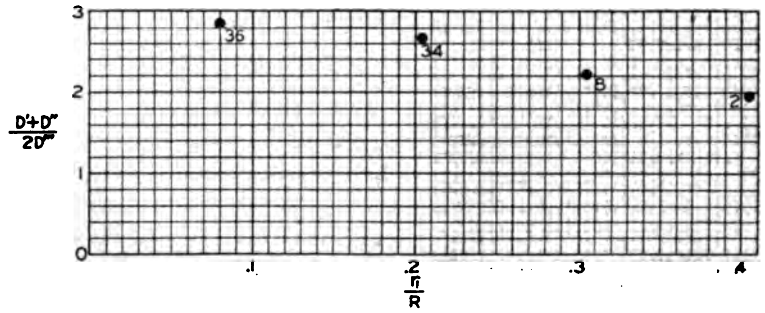


FIGURE 8.—Graph showing flatness and roundness ratios of pebbles of group C. For explanation, see figure 6.

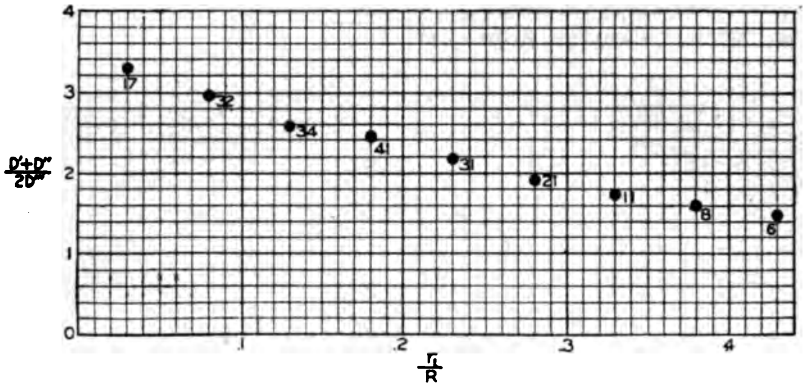


FIGURE 9.—Graph showing flatness and roundness ratios of pebbles of groups A, B, and C combined. For explanation, see figure 6.

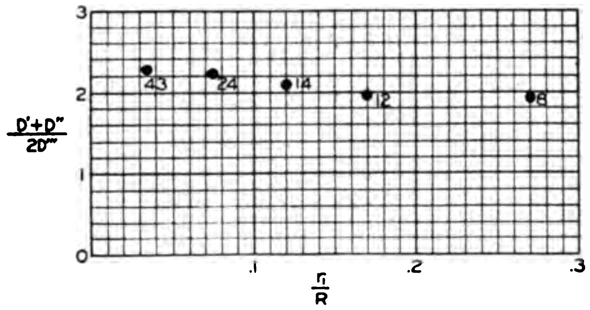


FIGURE 10.—Graph showing flatness and roundness ratios of pebbles of group D. For explanation, see figure 6.

Method of computing averages for subgroups.

Graph.	Group.	Subgroup.	$\frac{r_1}{R}$	Method of computing averages.
Figures 5 and 6, five large dots at left...	A	1	0.01–0.05	X
		2	.06– .10	
		3	.11– .15	
		4	.16– .20	
		5	.21– .25	
Figures 5 and 6, large dot at right..	A	6	.26 and over	Y
Figure 7, all dots....	B	7	.06– .15	X
		8	.16– .25	
		9	.26– .35	
		10	.36– .45	
Figure 8, all dots....	C	11	.01– .15	X
		12	.16– .25	
		13	.26– .35	
		14	.36– .45	
Figure 9, all dots....	A,B,C	15	.01– .05	X
		16	.06– .10	
		17	.11– .15	
		18	.16– .20	
		19	.21– .25	
		20	.26– .30	
		21	.31– .35	
		22	.36– .40	
		23	.41– .45	
Figure 10, four dots at left............	D	24	.02– .05	X
		25	.06– .09	
		26	.10– .14	
		27	.15– .19	
Figure 10, dot at right.............	D	28	.20– .45	Y

Roundness and flatness ratios of pebbles.

Group A, figures 5 and 6.

Subgroup.	$\frac{r_1}{R}$	$\frac{D'+D''}{2D'''}$	Abscissa and ordinate.
1..........	0.01	2.7	Method X, abscissa 0.03; ordinate (32.3÷9) 3.59.
	.05	2.2	
	.03	3.6	
	.03	3.0	
	.03	4.1	
	.05	3.8	
	.05	4.6	
	.05	3.4	
	.03	4.9	
		32.3	
2..........	.07	3.9	Method X, abscissa 0.08; ordinate (49.0÷14) 3.50.
	.07	2.7	
	.09	2.9	
	.08	6.5	
	.08	1.8	
	.10	6.3	
	.06	5.2	
	.06	2.5	
	.10	3.0	
	.09	2.1	
	.07	5.5	
	.09	2.0	
	.09	2.0	
	.06	2.6	
		49.0	

Roundness and flatness ratios of pebbles—Continued.

Group A, figures 5 and 6—Continued.

Subgroup.	$\frac{r_1}{R}$	$\frac{D'+D''}{2D'''}$	Abscissa and ordinate.
3..........	0.12	3.1	Method X, abscissa 0.13; ordinate (35.5÷13) 2.73.
	.12	1.7	
	.11	3.4	
	.12	5.0	
	.11	1.5	
	.12	4.0	
	.12	3.5	
	.12	2.2	
	.11	2.5	
	.15	2.2	
	.12	2.0	
	.13	2.9	
	.11	1.5	
		35.5	
4..........	.17	2.9	Method X, abscissa 0.18; ordinate (25.2÷9) 2.80
	.19	5.5	
	.18	3.0	
	.19	5.0	
	.18	2.0	
	.19	2.5	
	.20	1.4	
	.19	1.2	
	.17	1.7	
		25.2	
5..........	.22	2.5	Method X, abscissa 0.23; ordinate (14.9÷7) 2.13.
	.22	2.8	
	.21	2.0	
	.24	2.1	
	.25	1.6	
	.25	2.4	
	.24	1.5	
		14.9	
6..........	.28	2.5	Method Y, abscissa (3.20÷9) 0.355; ordinate (16.7÷9) 1.86.
	.26	2.5	
	.32	1.9	
	.40	1.3	
	.40	2.2	
	.50	1.2	
	.30	1.9	
	.36	1.3	
	.38	1.9	
	3.20	16.7	

Group B, figure 7.

Subgroup.	$\frac{r_1}{R}$	$\frac{D'+D''}{2D'''}$	Abscissa and ordinate.
7.........	0.13	1.3	Method X, abscissa 0.105; ordinate (19.7÷11) 1.79.
	.08	1.9	
	.09	1.7	
	.14	1.4	
	.09	1.8	
	.13	1.5	
	.09	3.2	
	.13	2.2	
	.11	1.8	
	.14	1.6	
	.15	1.3	
		19.7	

Roundness and flatness ratios of pebbles—Continued.

Group B, figure 7—Continued.

Subgroup.	$\frac{r_1}{R}$	$\frac{D'+D''}{2D'''}$	Abscissa and ordinate.
8	0.19	1.7	Method A, abscissa 0.205; ordinate (37.4÷22) 1.70.
	.25	2.0	
	.23	2.1	
	.21	2.6	
	.22	2.2	
	.23	1.2	
	.24	1.4	
	.18	1.6	
	.19	1.9	
	.25	1.2	
	.18	1.5	
	.16	1.6	
	.20	1.6	
	.19	1.2	
	.16	1.2	
	.19	1.8	
	.25	1.4	
	.23	2.2	
	.22	1.2	
	.16	1.9	
	.21	2.0	
	.22	1.9	
		37.4	
9	.32	2.0	Method X, abscissa 0.305; ordinate (32.5÷20) 1.63.
	.26	1.4	
	.34	1.5	
	.30	1.5	
	.26	1.6	
	.26	1.8	
	.26	1.8	
	.34	1.8	
	.28	1.7	
	.32	1.8	
	.30	1.6	
	.26	2.0	
	.26	1.9	
	.32	1.8	
	.28	1.4	
	.26	1.7	
	.30	1.1	
	.32	1.1	
	.32	1.5	
	.28	1.5	
		32.5	
10	.45	1.3	Method X, abscissa 0.405; ordinate (9.9÷7) 1.41.
	.40	1.5	
	.38	1.4	
	.42	1.3	
	.40	1.2	
	.45	1.6	
	.45	1.6	
		9.9	

Group C, figure 8.

Subgroup.	$\frac{r_1}{R}$	$\frac{D'+D''}{2D'''}$	Abscissa and ordinate.
11	0.05	2.5	
	.03	2.0	
	.02	2.3	
	.04	3.2	
	.05	3.3	
	.02	3.8	
	.04	3.4	

Roundness and flatness ratios of pebbles—Continued.

Group C, figure 8—Continued.

Subgroup.	$\frac{r_1}{R}$	$\frac{D'+D''}{2D'''}$	Abscissa and ordinate.
11.—Contd.	0.05	3.2	Method X, abscissa 0.08; ordinate (102.7÷36) 2.85.
	.13	2.2	
	.08	1.8	
	.13	2.2	
	.14	3.1	
	.07	4.7	
	.10	1.2	
	.12	2.2	
	.10	2.4	
	.15	2.1	
	.10	1.5	
	.15	1.7	
	.08	3.9	
	.12	2.6	
	.08	2.3	
	.14	3.1	
	.12	2.2	
	.14	7.1	
	.15	3.3	
	.14	3.0	
	.10	2.7	
	.14	3.7	
	.07	3.4	
	.09	2.4	
	.08	2.3	
	.09	3.9	
	.11	3.7	
	.08	2.0	
	.13	2.2	
		102.7	
12	.16	2.2	Method X, abscissa 0.205; ordinate (90.5÷34) 2.66.
	.16	1.2	
	.25	4.3	
	.22	2.5	
	.16	1.7	
	.20	4.0	
	.16	1.8	
	.18	2.8	
	.20	1.8	
	.22	3.5	
	.17	1.9	
	.21	4.5	
	.24	2.5	
	.18	5.3	
	.18	2.1	
	.23	1.8	
	.17	1.7	
	.22	1.7	
	.22	1.7	
	.16	1.9	
	.18	2.3	
	.23	1.3	
	.17	3.1	
	.19	2.0	
	.16	2.7	
	.19	5.5	
	.25	3.2	
	.18	2.5	
	.20	2.8	
	.18	3.2	
	.25	2.0	
	.16	2.3	
	.17	3.5	
	.17	3.2	
		90.5	

Roundness and flatness ratios of pebbles—Continued.

Group C, figure 8—Continued.

Subgroup.	$\frac{r_1}{R}$	$\frac{D'+D''}{2D'''}$	Abscissa and ordinate.
13	0.32	1.5	Method X, abscissa 0.305; ordinate (17.7÷8) 2.21.
	.26	2.1	
	.28	3.3	
	.26	2.7	
	.34	1.8	
	.26	2.1	
	.26	1.9	
	.26	2.3	
		17.7	
14	.45	1.9	Method X, abscissa 0.405; ordinate (3.9÷2) 1.95.
	.40	2.0	
		3.9	

Groups A, B, and C combined, figure 9. [a]

Subgroup.	$\frac{r_1}{R}$	$\frac{D'+D''}{2D'''}$	Abscissa and ordinate.
15	......	56.0	Abscissa 0.03; ordinate (56.0÷17) 3.29.
16	......	95.1	Abscissa 0.08; ordinate (95.1÷32) 2.98.
17	......	88.1	Abscissa 0.13; ordinate (88.1÷34) 2.59.
18	......	100.4	Abscissa 0.18; ordinate (100.4÷41) 2.45.
19	......	67.6	Abscissa 0.23; ordinate (67.6÷31) 2.18.
20	......	40.1	Abscissa 0.28; ordinate (40.1÷21) 1.91.
21	......	19.0	Abscissa 0.33; ordinate (19.0÷11) 1.73.
22	......	12.8	Abscissa 0.38; ordinate (12.8÷8) 1.60.
23	......	8.9	Abscissa 0.43; ordinate (8.9÷6) 1.48.

Group D, figure 10.

Subgroup.	$\frac{r_1}{R}$	$\frac{D'+D''}{2D'''}$	Abscissa and ordinate.
24	0.02	2.1	
	.02	2.5	
	.03	2.3	
	.03	1.8	
	.03	1.8	
	.04	2.7	
	.05	2.9	
	.05	1.9	
	.04	2.7	
	.02	2.3	
	.03	1.6	
	.02	2.4	
	.03	1.9	
	.02	2.7	
	.03	2.5	
	.04	1.8	
	.02	3.1	
	.02	2.8	
	.05	4.0	
	.04	1.7	
	.05	1.5	
	.05	2.0	
24.—Contd.	0.03	1.8	Method X, abscissa 0.035; ordinate (97.1÷43) 2.26.
	.03	2.0	
	.04	2.7	
	.04	2.4	
	.02	1.6	
	.04	2.4	
	.05	2.2	
	.04	1.1	
	.04	1.7	
	.05	2.0	
	.04	1.4	
	.04	3.1	
	.04	3.3	
	.05	1.4	
	.02	2.0	
	.04	2.7	
	.03	1.7	
	.03	3.6	
	.05	2.6	
	.03	2.0	
	.03	2.4	
		97.1	
25	.06	1.6	Method X, abscissa 0.075; ordinate (53.6÷24) 2.23.
	.09	1.2	
	.09	2.0	
	.07	1.7	
	.06	2.7	
	.06	2.9	
	.09	1.2	
	.06	3.0	
	.09	1.8	
	.07	1.7	
	.07	1.8	
	.07	3.5	
	.07	1.3	
	.07	1.8	
	.06	2.4	
	.06	2.2	
	.08	1.6	
	.09	2.9	
	.08	2.2	
	.08	1.4	
	.09	3.2	
	.08	1.3	
	.08	4.2	
	.07	4.0	
		53.6	
26	.12	1.7	Method X, abscissa 0.12; ordinate (29.3÷14) 2.09.
	.12	1.8	
	.10	2.5	
	.13	2.0	
	.12	1.2	
	.14	2.1	
	.13	2.2	
	.12	2.1	
	.10	1.4	
	.11	1.7	
	.10	1.7	
	.10	3.0	
	.12	2.7	
	.14	3.2	
		29.3	

[a] The averages for subgroups 15 to 23 were computed by method X. The measurements for the individual pebbles that fall in the subgroups are given above and are therefore not repeated. The figures in the third column represent the totals from which the averages were obtained.

Roundness and flatness ratios of pebbles—Continued.

Group D, figure 10—Continued.

Subgroup.	$\frac{r_1}{R}$	$\frac{D'+D''}{2D'''}$	Abscissa and ordinate.
27	0.15	1.4	Method X, abscissa 0.17; ordinate (23.7÷12) 1.97.
	.17	2.9	
	.19	2.2	
	.19	1.2	
	.16	1.8	
	.16	1.7	
	.15	3.2	
	.15	1.2	
	.18	3.1	
	.17	1.1	
	.16	2.5	
	.16	1.4	
		23.7	
28	.23	1.7	Method Y, abscissa (2.17÷8) 0.271; ordinate (15.4÷8) 1.92.
	.30	2.7	
	.20	2.2	
	.45	1.8	
	.34	2.0	
	.20	1.6	
	.24	1.9	
	.21	1.5	
	2.17	15.4	

It is evident that in each one of the five groups of pebbles the flatness and roundness of edges stand in inverse relation—that is, the more rounded the edges the less flat the pebbles. It is valid to assume that the pebbles with rounder edges have been longer affected by wave action than those with sharper edges. The former, which have been on the beach longer, are less flat than the latter, which have been a shorter time on the beach and are nearer to their original shape. It is conclusively proved that at these two beaches the pebbles become less flat as abrasion proceeds and that any predominance of flat, discoid forms is to be attributed to the flatness of the original fragments resulting from the current processes of disruption. Likewise the rather common roller-shaped cobbles and pebbles are the result of the rounding and smoothing of original elongate fragments, as suggested by the series shown in Plate XXVI, *C*, and evidence that these shapes are the result of any special sort of abrasion or motion was not seen by the writer.

The data are insufficient to warrant drawing ideal curves correlating the diminution of flatness with the increase of roundness, but the definite trend described above is established for the two localities visited. In figures 11 and 12 are shown diagrammatically the average shapes of the extreme pebble subgroups at the two localities with regard to both the flatness and the roundness. In each of these figures the flatness and roundness shown in the upper and lower diagrams are those of the subgroups represented by the dots at the extreme left and extreme right of figures 8 and 10, respectively. It will be noted that the Nantasket material yields flatter original fragments than that at Fort Hale. This is a result of factors related to the structure of the rocks and the processes and conditions of disruption. The writer has not yet made a study of this important aspect of the problem.

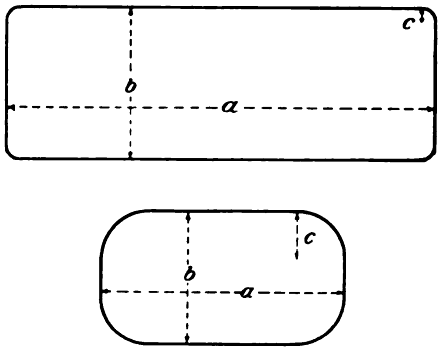


FIGURE 11.—Diagrams showing average flatness and roundness of most angular and most rounded subgroups of pebbles of group C at Nantasket, Mass. Top diagram represents those values for the average of the 36 pebbles of the left-hand subgroup of figure 8. Bottom diagram represents these values for the two pebbles of the right-hand subgroup of figure 8.

$$\frac{a}{b}=\frac{D'+D''}{2D'''} \qquad \frac{C}{\frac{1}{2}\sqrt[3]{a^2b}}=\frac{r_1}{R}$$

Sizes are arbitrary, but dimensions show true flatness and roundness ratios as indicated in the equation above.

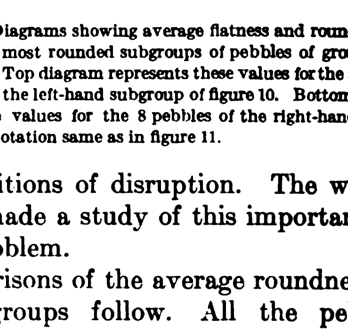


FIGURE 12.—Diagrams showing average flatness and roundness of most angular and most rounded subgroups of pebbles of group D at Fort Hale, Conn. Top diagram represents these values for the average of the 43 pebbles of the left-hand subgroup of figure 10. Bottom diagram represents these values for the 8 pebbles of the right-hand subgroup of figure 10. Notation same as in figure 11.

Comparisons of the average roundness of the several groups follow. All the pebbles of group B and some of those of group A are at an unknown distance from their source, and little can be said about them except that they are rounder as a whole than those of groups C and D shown in figures 8 and 10. Between those of groups C and D an interesting comparison can be made. The pebbles of group C are much rounder and indicate more travel or abrasion than those of group D. On comparing the average roundness of the two groups on the basis of his previous studies of the relation between abrasion and the roundness ratio[9] the writer finds that the pebbles of group C (Nantasket) indicate greater wear by abrasion than those of group D (Fort Hale) in the approximate ratio of 3.4 to 1. It was found by abrasion tests, however, that the Nantasket rock requires much more abrasion to produce a given degree of rounding than the Fort Hale rock. The ratio is approximately 5. On multiplying this ratio by the ratio given above, we find that the average pebble at Nantasket represents about 17 times the amount of abrasion that those at Fort Hale have received. The ratio is a result of two factors—the violence of wave action and the effectiveness of retention of the same pebbles in the zone of wave action.

Although the writer has ventured to express the ratios in numerical form, he does not wish to convey any false impression as to their accuracy. He is aware, probably more clearly than the reader, of the extreme complexity of the problem, which involves a large number of unknown factors. The figures given are believed to be within 25 per cent of the truth, and it is hoped they may provoke more accurate and extensive investigation.

ACKNOWLEDGMENTS.

In conclusion, acknowledgment is due to Dr. J. B. Woodworth, of Harvard University, for his kindness in guiding the writer to the Nantasket Beach locality and for his advice and comment during two days of field work on the Massachusetts coast; and to Mr. J. S. Brown, of the United States Geological Survey, who suggested the Fort Hale locality.

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[9] Wentworth, C. K., The shapes of pebbles: U. S. Geol. Survey Bull. 730, pp. 91-114, 1922.

A GEOLOGIC RECONNAISSANCE IN THE GULF COASTAL PLAIN OF TEXAS, NEAR THE RIO GRANDE.

By A. C. TROWBRIDGE.

INTRODUCTION.

During June, July, and August, 1919, part of June and all of July and August, 1920, and parts of July and August, 1921, the writer, assisted by A. G. Maddren in 1919 and by W. S. Glock and Lloyd North in 1920, and associated with L. W. Stephenson, E. W. Berry, E. B. Stiles, and Señor Enrique Díaz Lozano in 1921, carried on reconnaissance work along the Rio Grande in the southern extremity of Texas. As there seems to be immediate need for a map and a brief description of the formations on the Texas side of the Rio Grande, to serve as a key for important stratigraphic work in progress both in the United States and Mexico, it has been decided to prepare and publish now a preliminary report and map, which will show the general results of the work already done.

For aid in the preparation of this report the writer is indebted to Dr. T. W. Vaughan, under whose direction the field studies were made and the report was prepared; to Dr. Julia Gardner, who identified the molluscan faunas; to Prof. E. W. Berry, who aided in the collection of the floras and identified them; to Dr. J. A. Udden, who kindly supplied well logs from the files of the Bureau of Economic Geology and Technology of the University of Texas; to Mr. C. L. Baker, with whom the writer has carried on correspondence and from whom he has received information and suggestions; to Mr. G. C. Matson, who has already covered the field and whose field notes and maps were available for the writer's use; to Mr. E. T. Dumble, who freely gave his opinion on several difficult questions; and to Mr. Alexander Deussen, who by oral conference and by correspondence gave valuable assistance. Eighty-two published articles that bear more or less directly on the problems of the region were freely consulted.

GEOGRAPHY OF THE REGION.

The region here considered is bordered on the south and west by the Rio Grande which forms the International Boundary, a part of its eastern border is the Gulf of Mexico, and on the northwest and north it is limited by the line of contact between the Cretaceous and Tertiary systems as mapped by Stephenson.[1] Roughly sketched, this line of contact extends from a point about 5 miles south of Uvalde, in Uvalde County, westward and southwestward through Pulliam, in the same county, and thence southwestward and southward through Maverick County to a point on the Rio Grande about 3 miles north of the Maverick-Webb county line and about 35 miles downstream from Eagle Pass. The eastern, northeastern, and northern boundary of the area considered is represented by a line drawn from a point about 5 miles south of Uvalde nearly southward to Carrizo Springs, in Dimmit County, thence southeastward to Hebbronville, in Jim Hogg County; thence eastward through Falfurrias, in Brooks County, and Sarita, in Willacy County, to the Gulf of Mexico. This line corresponds in part with the south and west boundary of a large area southwest of Brazos River that was surveyed by Deussen, whose report is now in press.[2] The counties included in the Rio Grande region are extreme south-central Uvalde, western Zavalla, eastern Maverick, western Dimmit, and all or most of Webb, Zapata, Jim Hogg, Starr, Brooks, Hidalgo, Willacy, and Cameron. The total area considered is about 13,500 square miles, nearly one twentieth of the State of Texas.

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[1] Stephenson, L. W., The Cretaceous-Eocene contact in the Atlantic and Gulf Coastal Plain: U. S. Geol. Survey Prof. Paper 90, pl. 15, 1915.

[2] Deussen, Alexander, Geology of the Coastal Plain region of Texas: U. S. Geol. Survey Prof. Paper 126.

The region defined above lies wholly within the Rio Grande Plain of Hill and Vaughan.[3] The Balcones faulted zone, which separates this plain from the Edwards Plateau, lies 20 to 75 miles north of the Cretaceous-Eocene line. At the landward edge of the territory the elevation above the Gulf averages about 800 feet, and from this elevation there is a gradual slope to sea level at the Gulf. Although no part of the region has high relief, the part along the Rio Grande from the Webb-Maverick county line to Fort Sam Fordyce is notably rougher than that farther away from the river and that along the Gulf.

The rough belt near the river is commonly spoken of as "the breaks of the Rio Grande," and its roughness is due to the erosional work done by many intermittent tributaries. The width of the belt is not the same throughout but is determined in any area by the length of the tributary streams there. These streams average not more than 15 miles in length, but as most of them have only shallow valleys in their upper stretches the "breaks'' they form are generally less than 15 miles wide. Although the relief at most places in this belt does not exceed 100 feet, there are localities where the tops of the highest hills stand more than 250 feet above the Rio Grande. In general both the relief and the roughness decrease with the decrease in average altitude downstream. It is in this belt that the best and the most numerous exposures of the rock formations are found.

The more nearly flat land east of the "breaks" is divided into two parts by a conspicuous cuesta known as the Bordas scarp. This scarp and the trench cut by the Rio Grande are the only notable topographic features of the region.

The Bordas scarp crosses the northeast border of the territory mapped at a point 7 miles northeast of Torrecillas, about 38 miles east of Laredo and 100 miles from the Gulf, and from this point it extends southwestward to Torrecillas, thence southward to Ojuelos, and thence in a somewhat irregular course, generally southward and a bit eastward, and is cut through by the Rio Grande at Rio Grande City. In general the scarp follows the course of the base of the Reynosa formation, whose resistant rocks produced it. As the land slopes steeply westward and almost imperceptibly eastward from its crest this scarp is conspicuous only if viewed from the west.

The area between the breaks of the Rio Grande and the Bordas scarp is not rough. Its gentle southward and eastward (Gulfward) slope is broken only by shallow valleys of the heads of tributaries of the Rio Grande, the many low hills due to the outcrops of the lenses of rock slightly more resistant to subaerial erosion (which is here of slight effect), and the scattered depressions scooped out by the wind and the corresponding slight elevations formed by material blown from the depressions. Few square miles in this plain have a relief of as much as 50 feet, and some of them, so far as the eye can see, are almost flat.

Except an area of sand dunes, which covers about 2,800 square miles, chiefly in Willacy, Brooks. Hidalgo, and Jim Hogg counties, and a narrow strip extending for 20 miles along the river between Rio Grande City and Sam Fordyce, the part of the region east of the Bordas scarp is notably flat. The areas near the scarp, however, are slightly more undulatory than the areas near the coast, where the surface generally stands less than 50 feet above sea level and where there is no visible relief except that produced by an occasional "clay butte" or a shallow stream channel or "resaca." This smoothness, however, is broken by the channel of the Rio Colorado, a distributary of the Rio Grande, which in places is 40 feet deep and has vertical walls.

In the sand belt the relief is measured by the heights of the dunes and the depths of the "blow-outs," but even there it does not exceed 25 feet on an average and 60 feet at a maximum.

The lower Rio Grande region, which is the southernmost part of the United States except southern Florida and the Florida Keys, receives much heat through insolation, and its temperature is therefore high. The average annual temperature is about 72° F., and the range is from 20° in January to 110° in July. The sensible heat of summer is greatly reduced by constant east winds of the monsoon type. The nights are comfortable, except a few during which cloudiness retards radiation and the wind dies down. The region is semiarid. There are long periods of drought, and when it does rain the water falls in great quantities, so that dry creek beds run full and roads become arroyos.

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[3] Hill, R. T., and Vaughan, T. W., Geology of the Edwards Plateau and Rio Grande Plain adjacent to Austin and San Antonio, Tex.: U. S. Geol. Survey Eighteenth Ann. Rept., pt. 2, pp. 193-322, 1898.

The rainfall in 1910 was 12 inches, in 1915 16 inches, and in 1916 14 inches. The rainfall at Eagle Pass in 1908 was 15.16 inches and in 1909 8.63 inches. At some places there was no rain at all for three years prior to the fall of 1918.

The vegetation, which varies in luxuriance with the rainfall, consists of wild grasses, mesquite, guajillo, catclaw, prickly pear, and other forms of cactus, and many other plants, which together make up what is known as chaparral or brush. Large trees are found only along the main streams, where pecans grow, and on dunes in the sand belt, which bear live oaks. The open grassy prairie on the coastal flats is broken here and there by dense thickets of low live oak brush.

STRATIGRAPHY.

GENERAL FEATURES.

The beds of rock dip at low angles Gulfward from the Cretaceous-Eocene line, and successively younger formations are therefore exposed at the surface in wide belts east and southeast of that line. The Rio Grande flows in general southeastward in a course that is oblique to the strike of the formations but that is at some places parallel with the strike and at others parallel with the dip. It flows from older to younger beds, but its gradient is so slightly less than the dip of the beds and so nearly parallel with the strike for considerable distances that the formations change only at intervals of many miles along the river.

The formations are of Tertiary and Quaternary age. Eocene formations, which lie unconformably on Cretaceous formations along the irregular north boundary, continue at the surface eastward along the Texas-Mexican Railroad as far as Torrecillas and southward and southeastward along the Rio Grande almost to Sam Fordyce. Oligocene and Miocene formations, which are exposed on the Gulf Coastal Plain farther north, do not outcrop in the lower Rio Grande region, the Oligocene probably because they do not exist here and the Miocene because they are covered by a great overlap of Pliocene rocks. Pliocene, Pleistocene, and Recent deposits are exposed at the surface over wide areas east of the Bordas scarp. (See Pl. XXVIII.)

CRETACEOUS SYSTEM.

Rocks of Cretaceous age crop out extensively in the Edwards Plateau, in the northern part of the Gulf Coastal Plain, and elsewhere in Texas, and form a great system, but these areas lie outside of the region here described. This system in Texas has long been well known, chiefly through the earlier work of R. T. Hill.[4] More recently Udden [5] and his assistants have published a summary of the geology of Texas, in which the Cretaceous rocks are classified, described, and interpreted, and L. W. Stephenson is now completing certain work north of the Cretaceous-Eocene line.

THE CRETACEOUS-EOCENE LINE.

As Stephenson [6] has recently reported on the contact between the rocks of the Cretaceous and the Tertiary system in the lower Rio Grande region, the writer gave relatively little attention to this line of stratigraphic division. The line is shown on the map essentially as it was drawn by Stephenson, and the contact, at least between the Rio Grande and Nueces River, is essentially as he describes it. There is no marked lithologic break at the contact, though Stephenson found evidence of physical unconformity in Texas, as did Baker [7] on the Mexican side of the border, but the systemic significance of such unconformities is difficult to recognize, especially in parts of the geologic column where locally unconformities are common. The faunal break, however, is great and its significance is unquestionable. Not a single species is common to the faunas below and above the break and many genera that occur in the Cretaceous are missing in the Eocene. As Vaughan [8] pointed out in 1900, it is clear that the unconformity at this horizon is really great, even though lithologically and stratigraphically it appears insignificant. In the Rio Grande region a long time must have elapsed between the end of the recorded Cretaceous and the beginning of the recorded Eocene.

TERTIARY SYSTEM.

EOCENE SERIES.

The history of Eocene classification in the West Gulf Coastal Plain has been long and complicated. Many synonymous and overlapping formation names have been used, and correlations have been made which have later been found to be incorrect. The following classification seems to represent the present knowledge of the Eocene series in this region:

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[4] Hill, R. T., The Texas section of the American Cretaceous: Am. Jour. Sci., 3d ser., vol. 34, pp. 287-309, 1887.

[5] Udden, J. A., Baker, C. L., and Böse, Emil, Review of the geology of Texas: Texas Univ. Bull. 44, 1916.

[6] Op. cit., pp. 169-181.

[7] Baker, C. L., personal communication.

[8] Vaughan, T. W., Reconnaissance in the Rio Grande coal fields of Texas: U. S. Geol. Survey Bull. 164, pp. 35-36, 1900.

Frio clay
Fayette sandstone } (of Jackson age).
Claiborne group:
  Yegua formation.
  Cook Mountain formation.
  Mount Selman formation.
Wilcox group:
  Bigford formation (chiefly contemporaneous with Carrizo sandstone but in part younger).
  Carrizo sandstone.
  Indio formation.
Midway formation.

These formations are lithologically so very similar that their discrimination as units in mapping is extremely difficult, and the lines of contact shown on the map should therefore be considered only tentative, though there are slight differences in the rocks, which, taken together with their more significant faunas and floras make it possible to separate the formations with some confidence.

MIDWAY FORMATION.

Distribution.—The formation once known as the "Basal or Wills Point clays," now called the Midway formation, crops out only in a short and narrow belt in southern Maverick County. Its outcrop is not a continuous belt along the Cretaceous-Eocene line of contact, for it is overlapped in southern Uvalde, western Zavalla, and northeastern Maverick counties by strata of Wilcox age. The outcrop is also obscured by patches of gravel belonging to the Reynosa formation, of probable Pliocene age.

Relations to adjacent formations.—The Midway formation lies disconformably on the Escondido formation of the Cretaceous system. There is also a great time break at this horizon and another at the top of the Midway, where it is overlapped by strata of Wilcox age. The unconformable contact between the Midway below and the Wilcox above is well exposed (1) at the north end of the westward-facing bluff of the Rio Grande in extreme southern Maverick County, 2 miles north of the Webb County line, and (2) on the west wall of the valley of Frio River at Bob Evans's apiary (Myrick's lower apiary of the Uvalde folio), in Uvalde County, 12 miles east of the Rio Grande region, as mapped in this report. In each of these sections the line between the Midway and Wilcox formations is the edge of an erosional surface and the basal Wilcox is conglomeratic, the pebbles being worn fragments, fossils, and concretions of iron carbonate derived from the underlying Midway. There is a great unconformity between the Midway and the Reynosa, the gravels of the Reynosa having been deposited on a surface which bevels the Midway and all other Eocene strata.

Character.—The Midway formation consists chiefly of shale, but includes interbedded lenses and layers of sandstone and limestone. At the base of the formation in some places there are thin and discontinuous beds of conglomerate containing abraded fragments of rock and fossils derived from the underlying Escondido formation. Heavy ledges of limestone overlie the conglomerate or form the basal beds when there is no conglomerate. The limestone is gray, compact, and in some places crystalline, and it contains fossils. The beds are at few places more than 1½ feet thick and are interbedded with greenish-gray sand 1 to 2 feet thick. The shale is generally dark, and some beds are black, but the colors include green, brown, gray, bluish gray, and blue. Some of the beds are notably pure, but many are sandy or silty and gypsiferous. Individual beds do not exceed 40 feet in thickness. The beds of sandstone are gray, yellowish, brownish, or greenish, and are irregularly and thinly bedded. Many are micaceous and some are glauconitic. Most of them are rather soft, but some are firm. They vary in texture but are generally fine grained. Throughout the formation, but chiefly in the shale, there are numerous concretions, which range in diameter from 6 inches to 10 feet, are generally flat or biscuit-like, and consist chiefly of limestone. Many are septaria or "turtle stones." Some of the smaller ones are pyritized, some are clay ironstones, and some consist of iron carbonate.

A typical section of the formation on the Texas side of the Rio Grande, a mile below the Blessé ranch, on the Mexican side, is given below:

Section of the Midway formation in Texas near the Blessé ranch, Mexico.

	Feet.
Shale	7
Iron concretions	1
Shale	5
Concretionary sandstone	1
Blue-black shale with abundant *Venericardia smithii*	12
Concretionary iron bed containing *Venericardia smithii*	1

	Feet.
Dark-gray shale containing disc-shaped iron concretions and a few gastropods	25
Thin and irregularly bedded sandstone, interbedded near the top with sandy shale	15
	67

Thickness.—As the dip of the Tertiary formations may not be entirely deformational but may have been in part original, the usual methods of determining thickness from the outcrops are of no great value. In any case, the Midway formation is probably nowhere exposed in its full thickness because of the Wilcox overlap. Only where it has been drilled through for oil or water and where its base and top can be determined from the log or from samples of the core can its true thickness be estimated. Only one such boring is known in the Rio Grande region—the L. E. Hanchett oil-prospecting well, 10 miles west of Carrizo Springs. The log of this well shows that the formation is 194 feet thick. The average of all estimates of its thickness outside of the Rio Grande region but near it is 216 feet.

Fossils.—The fossils collected from the Midway formation of this and neighboring districts by the writer and others are listed below:

Aporrhais sp.
Callocardia ripleyana (Gabb).
Calyptrophorus velatus subsp. compressus Aldrich.
Cerithium penrosei Harris.
Cerithium? sp.
Crassatellites gabbi (Safford).
Cucullaea (macrodonta subsp.?) texana Gardner.
Cypraea sp.
Enclimatoceras vaughani Gardner.
Fusus ostrarupis Harris.
Leda milamensis Harris.
Lithophaga sp.
Mesalia pumila subsp. wilcoxiana Aldrich.
Mesalia sp.
Modiolus saffordi (Gabb)?
Natica sp.
Ostrea crenulimarginata Gabb.
Ostrea pulaskensis Harris.
Plejona limopsis (Conrad).
Plejona rugata (Conrad).
Pseudoliva ostrarupis Harris.
Teredo maverickensis Gardner.
Turris anacona (Harris).
Turritella alabamiensis Whitfield.
Turritella humerosa Conrad.
Turritella mortoni Conrad.
Turritella nerinexa Harris.
Venericardia bulla Dall.
Venericardia (alticostata subsp.?) hesperia Gardner.
Venericardia smithii Aldrich.
Venericardia (alticostata subsp.?) whitei Gardner.
Yoldia eborea (Conrad).

WILCOX GROUP.

SUBDIVISIONS.

A thick set of lithologically complex beds lies stratigraphically between the top of the Midway and the base of the Mount Selman formation. These beds have been variously known as the "Lignitic," the "Sabine," the "Sabine River," and the "Timber Belt," each of these names including all strata between the top of the "Basal clays" (Midway formation) and the base of the "Marine beds" (Claiborne group). Owen [9] first segregated a notably sandy phase of the "Lignitic" and called it the Carrizo sandstone, from the town of Carrizo Springs, where it is characteristically developed and well exposed. After the upper sands were separated and named the underlying beds were correlated with the Wilcox of Mississippi and called by the same name. Vaughan [10] considered the Carrizo formation a transgressive phase of the Wilcox. More recently Udden, Baker, and Böse [11] have tentatively considered it the oldest formation of the Claiborne group. In a still later geologic publication of the University of Texas Liddle [12] placed the Carrizo of Medina County in the Claiborne group without qualification. Deussen [13] found that it lay unconformably on Wilcox beds and unconformably beneath the Mount Selman formation between Brazos and Nueces rivers, and Baker [14] reported an unconformity between the Carrizo and underlying beds of Wilcox age on the Arroyo del Amole, on the Mexican side of the Rio Grande, across the river from the Chupadero ranch. As unconformities are common in the Wilcox and as neither the Wilcox nor the Carrizo contains fossils other than plants that had not been critically studied, the age of the Carrizo sandstone was an open question until 1921, when fossil plants were collected under the direction of E. W. Berry from the lower beds of the Wilcox, from the Carrizo, and from beds above the Carrizo but below the Mount Selman. As a result of these studies of the flora and an investigation of the lithology of the lignitic beds, the Wilcox is here recognized as a group, consisting of three formations, here named, in ascending order, the Indio formation, the Carrizo sandstone, and the Bigford formation.

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[9] Owen, J., Report of geologists for southern Texas: Texas Geol. and Min. Survey First Rept. Progress, for 1888, pp. 69-74, 1889.

[10] Vaughan, T. W., Index to the stratigraphy of North America (by Bailey Willis and others): U. S. Geol. Survey Prof. Paper 71, p. 726, 1912.

[11] Op. cit., pp. 83-84.

[12] Liddle, R. A., The geology and mineral resources of Medina County: Texas Univ. Bull. 1860, pp. 87-93, 1918 [1921].

[13] Deussen, Alexander, Geology of the Coastal Plain region of Texas: U. S. Geol. Survey Prof. Paper 126 (in press).

[14] Baker, C. L., personal communication.

INDIO FORMATION.

Name.—The strata overlying the marine Midway formation and underlying the Carrizo sandstone are here called the Indio formation. These strata have until now been known as the Wilcox formation, for they were believed to represent all the deposits of Wilcox age in this region. The new formation name is made necessary by the fact that the Wilcox as here developed becomes a group divisible into three formations, of which the Indio is the basal one. The Indio formation is named from the old Indio ranch, in Maverick and Dimmit counties, which includes most of the area of outcrop of the formation.

Character.—Although it is made up of an intricate mixture of sediments, the Indio formation consists chiefly of thin-bedded and laminated argillaceous sand and arenaceous shale but includes some layers of massive clay and lenses and layers of sandstone. The clay and shale are greenish or bluish gray and light chocolate-brown, and most of them are gypsiferous. The sandstone is gray, yellow, green, and brown, is not notably cross-bedded, and is of various textures. It includes also some beds of lignite and many calcareous and arenaceous concretions, most of them flat, biscuit-shaped, or millstone-shaped bodies.

Until recently no marine sediments have been found in the Wilcox group except along Sabine River, but the discovery of marine Foraminifera between 125 and 148 feet from the surface and 500 feet above the base of the Indio formation in the L. E. Hanchett oil drillings Nos. 1 and 2, about 10 miles west of Carrizo Springs, in Dimmit County,[15] shows that the Gulf advanced over the low-lying lands at least once for a short time during the Indio epoch. Beds of *Ostrea tasex* Gardner also are known west of the Hanchett wells and at and south of the Glass ranch headquarters, in Maverick County, and in the San Pedro sheep pasture, 19 miles southwest of Carrizo Springs, in Dimmit County. This form is similar to *O. crenulimarginata*, which is of Midway age, but is not identical with it. The oysters and the Foraminifera appear to occur at the same horizon.

The formation is partly marine and partly nonmarine and was deposited on both sides of a shore line on the landward side of which the land was low and on the opposite side of which the sea was shallow. The shore line probably oscillated back and forth slowly during Indio time.

Distribution.—The Indio formation crops out in the Rio Grande region in a belt 10 to 14 miles wide in western Dimmit, southeastern Maverick, and northwestern Webb counties, where it is exposed in practically its full thickness. Here it adjoins the Midway on the west and the Carrizo on the east. Farther north, in Maverick County, the Indio overlaps the Midway and rests upon the Cretaceous. Still farther north, in western Dimmit and Zavalla counties and eastern and northeastern Maverick County, the Indio is in turn cut out by a great overlap of the Carrizo on the Cretaceous. In the extreme northeast corner of the region the Indio crops out again between the Cretaceous and the Carrizo where Nueces River has cut through the overlying and overlapping Carrizo sandstone.

Thickness.—The thickness of the Indio recorded in the Hanchett wells, in Dimmit County, is 648 feet, and as these wells are only about a mile west of the eastern boundary of the formation at a point where the belt of outcrop is widest, the maximum thickness of the Indio exposed probably does not exceed 700 feet. Other layers that are covered by the Carrizo overlap may or may not overlie those which crop out.

Fossils.—With the exception of Foraminifera, oysters, and a few fossil leaves, the Indio formation is faunally and florally barren in the Rio Grande region. The protozoans include *Nodosaria*, *Textularia*, and *Globigerina*. The mollusks are *Ostrea tasex* Gardner and *Levifusus* sp. cf. *L. trabeatoides* Harris.

Fossil plants were found (1) on the west wall of the valley of Nueces River a mile below Pulliam ranch, (2) on the east wall of the valley of Nueces River at the big bend 1¼ miles above the Uvalde-La Pryor road crossing, (3) in the clay pit at the end of the unused aerial tram south of Elmendorf, Bexar County, and (4) at the Schuddemagen ranch, 10 miles south of Sabinal, Uvalde County. Localities 3 and 4 are outside the Rio Grande region. A list of identified species follows:

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[15] Well log and description of samples supplied independently by J. A. Udden and C. L. Baker.

Anona ampla Berry.
Anona eolignitica Berry.
Cyperites sp. Hollick.
Ficus mississippiensis Berry.
Nectandra sp.
Oreodaphne obtusifolia Berry.
Rhamnus coushatta Berry.
Sabalites grayanus Lesquereux.
Sapindus linearifolius Berry.

CARRIZO SANDSTONE.

Distribution.—The base of the Carrizo was located by Owen [16] at a point 10 miles west of Carrizo Springs, and the formation, which is made up of sandy beds, extended eastward to the base of the "Marine beds," east of Asherton, occupying a belt about 20 miles wide. When it is traced southward, however, the belt of sands becomes narrower until, at the Rio Grande, it is only 3 miles wide. The strata that cover it here are not prevailingly sandy and are what is here called the Bigford formation. North of Carrizo Springs the Carrizo formation spreads northwestward to the Cretaceous rocks, overlapping both the Indio and the Midway. Northeast of Carrizo Springs, outside the region shown on the map, the belt of Carrizo sandstone becomes narrower, the Bigford formation here also probably wedging in between the Carrizo and the Mount Selman.

Relations to adjacent formations.—The Carrizo sandstone rests unconformably upon the Indio by overlap. In the area east of the outcrop of the contact, however, where the full thickness of the Indio is represented, the similarity of the flora indicates that the relations are conformable. The relation between the Carrizo and the Bigford formation is apparently conformable. Differences in flora suggest a break between the Carrizo and the Mount Selman, and there are indications of unconformity where the two come together in the railroad cut 3 miles west of Big Wells, an exposure 15 miles east of the Rio Grande region.

Character.—The Carrizo formation is decidedly more sandy than the other formations of the Wilcox group, the Indio formation below and the Bigford formation above, and the beds of sandstone in the Carrizo are more firmly cemented. Some of them are cemented and crystallized into a good grade of quartzite. Many of them are highly ferruginous, but some are gray or white, colors denoting little iron. The sand and the sandstone are characteristically cross-bedded. Owing to inequalities from place to place in the firmness of the cement erosion has in some places produced castellated forms, notably south of Chupadero ranch, in northwesternmost Webb County. The sandy beds vary greatly in texture. In the quarries around Carrizo Springs and for some distance north of that place the rock is fine grained, but in many other localities it is medium and even coarse grained.

The Carrizo sandstone includes also thin beds and lenses of clay of various colors and beds of limestone, yellow on weathered surfaces and light chocolate-brown inside, forming concretions, rough beds, or lenses, botryoidal bodies, and irregular masses. Cone-in-cone structure is fairly common in the beds of fine texture in which calcareous and argillaceous material are mixed in about equal proportions.

Thickness.—The thickness of the Carrizo sandstone as estimated by Owen [17] is 200 feet. Between a point 10 miles west of Carrizo Springs and a point 3 miles west of Big Wells, however, its thickness is probably more than 400 feet, there being at least 200 feet of strata exposed west of Carrizo Springs. At the Rio Grande, where the sandy belt is narrow, its thickness is estimated at 118 feet. At another point between the river and Carrizo Springs it appears to be about 392 feet. Where the Carrizo overlaps the Indio and Midway north of Carrizo Springs it is doubtless very thin. The average of all previous estimates is 250 feet. It evidently varies greatly in thickness, and the average is now put at 325 feet.

Fossils.—Invertebrate and vertebrate fossils have not been found in the Carrizo sandstone. Poorly preserved fragments of plants have often been noted, but the flora was not critically studied until 1921, when E. W. Berry accompanied the writer to the field and made collections. Identifiable leaves were found in a short arroyo in the east wall of Nueces River valley three quarters of a mile below the Uvalde-La Pryor road crossing and in the Bell quarries, southwest of Carrizo Springs, from which Carrizo sandstone was taken to build the courthouse and other buildings in Carrizo Springs.

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[16] Owen J., Report of geologists for southern Texas: Texas Geol. and Min. Survey First Rept. Progress, for 1888, pp. 70-74, 1889.

[17] Owen, J., idem, p. 72.

The list given below shows, according to Berry, that the Carrizo is of Wilcox and not of Claiborne age, a fact which is in harmony with the lithology and stratigraphy of the sandstone and the associated beds.

Acrostichum sp.
Anona ampla Berry.
Anona wilcoxiana Berry.
Banksia puryearensis Berry.
Canavalia eocenica Berry?
Cassia tennesseensis Berry?
Cinnamomum vera Berry?
Dryophyllum tennesseensis Berry?
Eugenia grenadensis Berry.
Ficus mississippiensis (Lesquereux) Berry.
Gleditsiaphyllum eocenicum Berry.
Heterocalyx n. sp.
Mespilodaphne coushatta Berry.
Myrcia vera Berry.
Nectandra pseudocoriacea Berry.
Oreodaphne obtusifolia Berry.
Oreodaphne puryearensis Berry.
Palmocarpon butlerensis Berry.
Persea longipetiolatum (Hollick) Berry.
Sabalites grayanus Lesquereux.
Sophora wilcoxiana Berry.
Sterculia wilcoxensis Berry.

BIGFORD FORMATION.

Name and distribution.—Most of those who have visited this region have believed that the Carrizo sandstone is continuous from the top of the Indio formation (the old Wilcox formation) to the base of the Mount Selman, and it appears to be continuous at the type section of the Carrizo near Carrizo Springs and in that latitude, but south of Carrizo Springs the sand and sandstone of the Carrizo give place along the strike to clay, thin-bedded sandstone, and lignite. To these beds, which consist so largely of clay that they can not be called Carrizo sandstone, the name Bigford is here given, from Bigford ranch, which is practically the only habitation in their belt of outcrop, where the beds are well exposed along the river within the ranch. The outcrop widens toward the south from 2 miles at the boundary of the Rio Grande region, southeast of Carrizo Springs, to about 12 miles at the Dimmit-Webb county line. The Rio Grande has exposed the beds in its north bluffs for 20 miles. Between Carrizo Springs and Big Wells, outside of the Rio Grande region, the formation is entirely absent. It may wedge in farther north, for similar beds appear to occur in well logs and in exposures along Nueces River southeast of Crystal City.

Character.—Lithologically the Bigford formation consists chiefly of clay of many colors and of subordinate quantities of gray, green, and brown sandstone, which is at most places not cross-bedded. It contains many beds of lignite, the heaviest 20 inches thick, and some lens-shaped concretionary masses. It contains no paper shales and sands, such as occur in the Indio, nor any thick, cross-bedded, and commonly quartzitic sands, such as occur in the Carrizo.

Relations to adjacent formations.—Although the Bigford formation is at least fairly distinct lithologically, it is not believed to represent, except in its uppermost part, a period of time entirely separate from the Carrizo epoch. The greater part of the formation probably grades along the strike into beds in the middle and upper parts of the Carrizo sandstone, and if so is contemporaneous with those beds. At some places, however, the uppermost part of the Bigford rests with apparent conformity on the Carrizo sandstone. The Bigford strata appear to represent a lagoon and tidal-flat phase of a stage of deposition during which the Carrizo sandstone was deposited at or landward from the shore line.

Thickness.—The Bigford formation ranges in thickness from about 80 to about 470 feet.

Fossils.—The only fossils found in the Bigford formation are some leaves of a few species of plants, which were collected at a place on Concillas Creek a quarter of a mile below the point where it is crossed by the road from Bigford ranch to Apache ranch, about half a mile from the Rio Grande, where two sets of beds of clay, sandstone, lignite, and lignitic clay are separated by an erosional unconformity. Leaves occur both below and above the unconformity but were collected only from the upper set of beds, in which they are best preserved. The forms identified are as follows:

Anacardites grevilleafolia Berry.
Banksia puryearensis Berry.
Canna eocenica Berry.
Cassia marshallensis Berry.
Cyperites sp. Hollick.
Inga wickliffensis Berry?
Juglans schimperi Lesquereux.
Mimosites variabilis Berry.
Mimusops mississippiensis Berry.
Myrica wilcoxensis Berry.
Sabalites grayanus Lesquereux.
Sophora wilcoxiana Berry.

Berry reports that this is a Wilcox flora, one distinctly older than that in the base of the Mount Selman formation, which is of Claiborne age.

CLAIBORNE GROUP.

The "Marine beds" of earlier writers included the strata between the top of the "Lignitic" and the base of the Yegua. These beds are now separated into two formations, the almost unfossiliferous marine beds below constituting the Mount Selman formation and the highly fossiliferous marine strata above constituting the Cook Mountain formation. The overlying Yegua formation, which contains Claiborne fossils, is also included in the Claiborne group.

MOUNT SELMAN FORMATION.

Character.—The chief constituent of the Mount Selman formation is clay, and exposed sections of it are therefore rare except at places along drainage lines where thin ledges of sandstone and limestone hold up the clay in vertical faces. There are large flat areas where the formation is not exposed but where the shallow surficial drainage channels are so universally clayey that the underlying formation must be chiefly if not entirely clay or shale. The sections exposed probably exaggerate the proportion of sandstone in the formation, for they occur only where lenses of the more resistant materials are most abundant. The clay is gray, black, greenish gray, and bluish gray where fresh and yellow or buff where weathered. Some of the beds are sandy and some are limy, but most of them consist chiefly of stiff, compact clay, plastic and sticky when wet and hard but with a fracture like that of starch when dry. The beds of clay contain a large quantity of gypsum in lenses, beds, stringers, joint fillings, and irregular crystal aggregates. Most of it is the transparent platy variety, but some masses of bladed crystals are brown.

The sandstone occurs in layers and lenses, some of them 25 or 30 feet thick for short distances. The sand is coarse, medium, and fine, most of it is micaceous, and some is glauconitic. The beds are fairly well consolidated but are not quartzitic. The formation includes a few thin lenses of gray limestone.

Coal, both lignitic and bituminous, is a common constituent of the Mount Selman formation. It has been mined at Minero, Dolores, Cannel, and Santo Tomas, in Webb County. There are two main producing coal beds and several thinner beds, less pure, which are not worked. The coal beds here are about one-third of the distance from the top to the bottom of the formation, but beds occur nearer its base upstream from Palafox and almost at its top near the mouth of Arroyo Santa Isabella, and well logs show that coal beds occur throughout the whole thickness of the formation.

The Mount Selman formation contains throughout, from bottom to top, many calcareous concretions, chiefly in the clay and shale. Most of them are composed of compact, fine-grained, pure, almost lithographic limestone. On the outside they are pale yellowish gray or buff; on the inside they are light chocolate-brown or gray. Nearly all of them are septarian, and the fractures are filled with calcite. They are of diverse sizes and forms. The smallest are about the size of a pea and the largest are 6 feet in diameter; some are cylindrical, resembling pipe stems, some are biscuit-shaped, and some are nodular and extremely irregular. The average concretion is a foot in diameter and spheroidal in form.

Distribution.—The surficial distribution of the Mount Selman formation is shown on the map. The formation extends downstream along the Rio Grande from a point 6 miles above Palafox to the mouth of Sambarieto Creek, about 8 miles above Laredo, a distance of about 26 miles measured in a straight line. The course of the river is irregularly oblique to the strike, however, and this distance is not a measure of the width of the belt of outcrop, which is about 16 miles wide and of nearly uniform width. The western boundary of the formation, which is the Claiborne-Wilcox line of contact, is not sharply defined. In general it marks the line that separates beds of clay, sandstone, and lignite that contain no molluscan fossils and few concretions but that carry a Wilcox flora (the Bigford formation), from beds of gypsiferous, highly concretionary clay interbedded with beds of sandstone and limestone carrying unmistakable though few and fragmentary marine fossils. The Mount Selman-Cook Mountain line, on the east side of the belt, separates the Mount Selman material from the sandy, highly fossiliferous, red-weathering Cook Mountain formation, which stratigraphically overlies the Mount Selman.

The Mount Selman formation, though it contains marine rock, is evidently not entirely of marine origin. The coal and the sediments that carry land plants were doubtless deposited in isolated coastal basins and lagoons and perhaps to some extent on tidal flats.

Thickness.—The minimum measured thickness of the formation is 225 feet and the maximum is 707. Deussen assigns to it an average thickness of 350 feet in the area next north of the Rio Grande region. The average within the Rio Grande region is 618 feet.

Fossils.—The Mount Selman formation is not highly fossiliferous, yet a few poorly preserved forms of both animals and plants have been recognized. The mollusks so far recognized are *Cornulina armigera* Conrad, *Cytherea* sp. cf. *C. trigoniata* var. *winnensis* Harris, *Ostrea* sp., *Plejona petrosa* (Conrad), *Protocardia* sp., and *Venericardia planicosta* Lamarck.

Only two collections of Mount Selman plants were made by the writer. They are fragmentary and obscure, but Berry has identified them provisionally as *Apocynophyllum grevilleafolium* Berry, *Coccolobis claibornensis* Berry, *Ficus newtonensis* Berry, *Geonomites* n. sp., and *Myrcia* n. sp.

COOK MOUNTAIN FORMATION.

Distribution and relations.—The Cook Mountain formation is the upper and highly fossiliferous part of what has been known as the "Marine beds." Its outcrops lie in a belt averaging 13 miles in width where it includes the full thickness of the formation, extending from the northeast border of the region at and west of Encinal, almost due south for about 40 miles to a point where the base of the formation is cut off by a bend in the Rio Grande 8 miles above Laredo. From this point for a distance of about 70 miles down the river the strike of the formation is almost parallel to the general course of the river. The river cuts the top of the formation—the Cook Mountain-Yegua line—15 miles upstream from Roma. Thus the formation is exposed in the "breaks of the Rio Grande" for a distance of 75 miles. The towns included within the belt of outcrop are Encinal, Laredo, San Ygnacio, Zapata, and a large number of places inhabited by Mexicans.

This change in the strike from west of south to east of south so as almost to correspond with the course of the Rio Grande from Laredo to Roma was not known to all previous workers. Dumble,[18] for instance, continuing the west of south by east of north strike, draws the Cook Mountain-Yegua contact line across the river 8 miles below Laredo, the Yegua-Fayette line about 4 miles above Zapata, and the Fayette-Frio line on the Texas side a mile or two below Rio Grande City. The true structure was first pointed out by Vaughan,[19] who had collected Claiborne fossils far down the Rio Grande and understood that they came from the "Marine beds." Thus much of what Dumble has considered Fayette was recognized by Vaughan as Cook Mountain. This fact explains Dumble's insistence that much if not all of the Fayette formation is of Claiborne age.

Character.—The Cook Mountain formation is primarily sandy, and the sand is more or less firmly cemented. Most of the rock is medium grained, but there are beds of fine-grained and coarse-grained sandstone. The beds are brown, red, yellow, green, and gray and are commonly ferruginous, micaceous, and glauconitic. Many of them are cross-bedded and ripple marked. Interbedded with the sandstone is some yellowish, bluish, and greenish-gray or chocolate-colored clay and a few thin lenses of gray limestone. The sandstone and at some places the clay contains large, dark-gray, hard-centered, crystalline limestone concretions, some of which are fossiliferous. The lower two-thirds of the formation weathers characteristically into red sandy soils; the upper third at most places weathers gray. All the soils derived from the Cook Mountain formation support vegetation, which is unusually luxuriant.

Thickness.—The estimates of the thickness of the Cook Mountain formation range from 187 to 668 feet, and average 422 feet.

Fossils.—The formation everywhere contains abundant fossils, by which it can be distinguished from the Mount Selman below and the Yegua above; indeed it can thus be distinguished from all other formations in the region, for its faunas are larger and more diversified than those of any other Tertiary formation in Texas. The faunas within the formation present four more or less distinct facies.

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[18] Dumble, E. T., Geology of Southwestern Texas: Am. Inst. Min. Eng. Trans., vol. 33, p. 916, fig. 1, 1903.

[19] Vaughan, T. W., Contributions to the geology and paleontology of the Canal Zone, Panama, and geologically related areas in Central America and the West Indies: U. S Nat. Mus. Bull. 103, 1919.

One of these faunas is found at the base of the formation. The complete specific list is as follows:

Anomia ephippoides Gabb.
Buccinanops sp. cf. B. ellipticum Whitfield.
Callocardia astartoides Gardner.
Callocardia sp. cf. C. bastropensis (Harris).
Callocardia sp.
Cerithium texanum Heilprin.
Cerithium webbi Harris.
Corbula (Cuneocorbula) conradi Dall.
Drillia? sp.
Egerella sp.
Epitonium sp.
Lacinia alveata Conrad?
Leda sp.
Levifusus trabeatoides Harris?
Levifusus sp.
Lucina sp.?
Natica dumblei Heilprin.
Olivula staminea Conrad.
Olivula sp.
Ostrea alabamiensis subsp. georgiana Conrad (small).
Polynices arta (Gabb).
Pseudoliva vetusta Conrad.
Sinum declivum Conrad?
Solen sp.
Tuba antiquata Conrad.
Turritella sp.
Venericardia planicosta (Lamarck).
Yoldia sp. cf. Y. psammotea Dall.

A second fauna occurs in the lower part of the Cook Mountain formation but above the basal beds. A complete list of species follows:

Acteon pomilius Conrad.
Adeorbis? sp.
Anomia ephippoides Gabb.
Architectonica sp. aff. A. acuta Conrad.
Benoistia? sp.
Cadulus sp.
Callocardia astartoides Gardner.
Callocardia bastropensis (Harris).
Callocardia sp.
Cancellaria panones Harris.
Cancellaria sp.
Cardium (Cerastoderma) harrisi Vaughan?
Cardium (Cerastoderma) ouachitense Harris?
Cassis? sp.
Cerithium sp.
Cochlispira sp.
Corbula (Cuneocorbula) conradi Dall.
Crassatellites sp.
Crepidula sp.
Cylichna sp. cf. C. jacksonensis Meyer.
Drillia nodocarinata (Gabb)?
Drillia texacona Harris.
Egerella sp.
Epitonium trapaquara (Harris).
Eucheilodon sp. cf. E. reticulatoides Harris.
Eucheilodon? sp.
Lacinia alveata Gabb.
Latirus moorei Gabb?
Leda bastropensis Harris.
Leda compsa Gabb.
Lima harrisiana Aldrich.
Lucina sp. cf. L. ozarkana Harris.
Mesalia claibornensis Harris.
Murex (Odontopolys) sp.
Natica dumblei Heilprin (large).
Natica semilunata Lea.
Nucula mauricensis Harris.
Olivula staminea Conrad.
Ostrea alabamiensis subsp. georgiana Conrad (small).
Ostrea sellaeformis Conrad?
Ostrea sp.
Pholadomya sp.
Plejona petrosa (Conrad).
Plejona precursor (Dall)?
Plejona sp. cf. P. haleiana (Whitfield).
Plejona sp.
Polynices arata (Gabb).
Protocardia sp. cf. P. gambrina Gabb.
Pseudamusium sp.
Pseudoliva sp. cf. P. vetusta Conrad.
Pteropsis lapidosa Conrad.
Pyrula (Fusoficula) sp. cf. P. texana Harris.
Sinum declivum (Conrad).
Solen sp.
Surcula gabbi Conrad.
Teinostoma? sp.
Tellina mooreana Gabb?
Tellina sp. A.
Terebra texagyra Harris.
Terebra houstonia Harris.
Tornatina sp.
Tortoliva texana Conrad?
Tuba antiquata Conrad?
Turbonilla? sp.
Turricula sp.?
Turris sp.
Turritella nasuta Gabb.
Venericardia mooreana (Conrad).
Volvula sp.
Yoldia sp. cf. Y. psammotea Dall.
Yoldia sp.

The middle part of the Cook Mountain formation carries a third fauna, the names of the species of which follow:

Ancillaria sp.
Architectonica sp.
Callocardia astartoides Gardner.
Callocardia bastropensis Harris.
Callocardia sp.
Cancellaria sp.
Cerithium texanum Heilprin.
Corbula (Cuneocorbula) conradi Dall.
Corbula sp.
Diplodonta sp.

Distorsio septemdentata Gabb.
Drillia sp. cf. D. enstricina Harris.
Egerella sp.
Fusus sp.
Gaza? sp.
Lacinia alveata Conrad.
Latirus moorei Gabb?
Leda bastropensis Harris.
Levifusus sp.
Lucinia? sp.
Martesia sp.
Mesalia claibornensis (Conrad)?
Modiolus (Brachidontes) texanus (Gabb).
Natica dumblei Heilprin (large).
Natica dumblei Heilprin (small).
Natica semilunata Lea.
Olivula staminea Conrad?
Ostrea alabamiensis subsp. georgiana Conrad.
Ostrea sp.
Phos sagenus (Conrad)?
Pinna sp.
Plejona petrosa (Conrad).
Plejona sp.
Polynices arata (Gabb).
Psammobia? sp.
Pseudoliva ostrarupis subsp. pauper Harris.
Pseudoliva vetusta Conrad?
Pteropsis lapidosa Conrad subsp.?
Pteropsis sp.
Pyrula texana Harris?
Rimella sp. cf. R. texana Harris.
Siliqua sp.
Sinum declivum (Conrad)?
Sphaerella sp.
Surcula gabbi Conrad?
Teinostoma? sp.
Tellina sp. cf. T. mooreana Gabb.
Tellina sp. cf. T. tallecheta Harris.
Tellina sp. A?
Trinarcia declivis (Conrad).
Turris vaughani (Harris).
Turris sp.
Turritella nasuta Gabb.
Venericardia mooreana Gabb.
Venericardia sp.

Finally, a fourth Cook Mountain fauna is widely distributed at the top of the formation. This fauna marks the Cook Mountain-Yegua contact. The most prominent forms are a large variety of *Natica dumblei*, which is associated with *Ostrea georgiana*. Most of this fauna is contained in the limestone concretions, not all of which, however, carry fossils. Many of the shells have been rolled and abraded and perhaps concentrated before the concretions were formed. A list of the species making up this fauna follows:

Arca sp.
Callocardia astartoides Gardner.
Callocardia sp. cf. C. trigoniata Lea.
Calyptrophorus sp. cf. C. valatus Conrad.
Corbula (Cuneocorbula) conradi Dall.
Fusus? sp.
Natica dumblei Heilprin (large).
Ostrea sp.
Polynices arata (Gabb).
Polynices gibbosa (Lea).
Solen sp.
Tellina mooreana Gabb?
Tellina sp. A?
Tuba antiquata Lea?
Turritella sp.
Venericardia sp.

YEGUA FORMATION.

The Yegua, the youngest of the Claiborne formations, lies with some indications of unconformity upon the Cook Mountain and underlies the Fayette, of Jackson age.

Distribution.—The map shows the distribution of the formation at the surface in the lower Rio Grande region. The belt of outcrop varies in width from 4½ to 17 miles, the variation being probably due to an irregular overlap of the Fayette. The outcrop within the region is confined to Webb and Zapata counties and a small part of western Starr County.

Character.—About 90 per cent of the formation in this area appears to be dark gray, black, red, pink, purple, green, and brown selenitic carbonaceous clays. The predominant color is dark gray, and the material weathers into dark-gray clay soils. There are also many beds, lenses, and seams of soft gray and buff sands and sandstones, most of them thin. Dark, irregular limestone concretions occur sparingly in the clay.

Thickness.—The average thickness of the strata assigned to the Yegua outside the Rio Grande region is 817 feet, and the range is from 375 to 1,400 feet, but in this region the average thickness of the beds exposed, so far as it can be determined, is only about 406 feet.

Fossils.—Although Dumble [22] reports *Tellina mooreana* Gabb, *Turritella houstonia* Harris, and *Natica recurva* Aldrich from beds in Mexico identified as Yegua, it seems likely that the beds from which they were collected should be included in the Cook Mountain of the Rio Grande region. Leaves are also reported to have been found in the formation at places outside the region, but none was found inside. The only fossil seen in the Yegua in the region covered by this report is *Ostrea georgiana*, and even this occurs more sparingly in the Yegua than in the Cook Mountain below or the Fayette above. In the Rio Grande region the deposits classified as Yegua are more closely allied faunally with the Jackson than with the Claiborne, but elsewhere the reverse is true. Possibly only the upper part of the Yegua occurs here, and this part may be really of Jackson age. Until this can be demonstrated, however, the Yegua will all be classed as of Claiborne age.

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[22] Dumble, E. T., Tertiary deposits of northeastern Mexico: California Acad. Sci. Proc., 4th ser., vol. 5, No. 6, p. 177, 1915.

FAYETTE SANDSTONE.

Character.—The materials of the Fayette formation are fairly characteristic, although they are lithologically like those of the Cook Mountain formation, with which they are likely to be confused, but the fauna and flora are definite and on the whole the formation is not difficult to recognize in the field.

The Fayette contains more sand and sandstone than any other kind of rock, yet it is not so sandy in the Rio Grande region as it is farther north and east. The sandstone is exceedingly variable—in color almost white, gray, greenish gray, buff; in texture fine, medium, and coarse; in consolidation ranging from loose sand to quartzitic sandstone. The most characteristic feature of the sandstone is that it is fossiliferous. It is commonly laminated and cross laminated in intricate patterns. Interbedded with the arenaceous beds there are many beds and lenses of sandy and limy greenish-gray, pink, and red shale and clay. Limestone is scarce but not entirely absent. Beds of white volcanic ash are found in the formation at several places. Large, dark, crystalline limestone concretions are common. Silicified wood occurs abundantly, chiefly in the clays but in the sandstones as well. Most of the silica is opal, but chalcedony is found also. The silicified wood is characteristic of the formation in this region.

Thickness.—The thickness of the formation in this region averages not more than 360 feet, about 100 feet less than the average thickness elsewhere.

Fossils.—The formation contains a single identifiable fossil, a large variety of *Ostrea georgiana* Conrad. The rich Claiborne fauna attributed to the Fayette by Dumble is Cook Mountain, as explained on page 94, but a number of species of fossil plants are found in the ash beds and some in the sandstones. The best collections were obtained at points 2½ and 4½ miles north of Miraflores ranch, in Zapata County. Berry has identified the following forms:

Apocynophyllum 2 n. sp.
Bombacites n. sp.
Cinnamomum sp.
Coccolobis n. sp.
Conocarpus eocenicus Berry.
Diospyros n. sp.
Inga n. sp.
Mespilodaphne n. sp.
Myristica catahoulensis Berry (?).
Nectandra n. sp.
Papilionites n. sp.
Pisonia n. sp.
Sabalites vicksburgensis Berry.
Sapindus dentoni Lesq.
Sapotacites n. sp.
Spohora claibornensis Berry (?).
Terminalia phaeocarpoides Berry.
Ternstroemites n. sp.

Berry regards these plants as of middle or upper Jackson age and states that they indicate a warm, probably subtropical climate, with local or seasonal aridity, probably without general deficiency in rainfall. Although some of the formation is marine, much of it, as the plants suggest, was doubtless deposited subaerially on coastal sandy and clayey plains. The character of much of the formation indicates deposition in shallow water that was subject to considerable agitation.

FRIO CLAY.

In the Frio formation there are 100 to 400 feet of gray, greenish and yellowish gray, red, pink, and blue pure and sandy clays and a very few seams of gray sandstone, 1 to 8 inches thick. Perhaps the pink color, doubtless due to weathering, predominates in the exposures, practically all of which are shallow. Nearly everywhere the clay is checked by joints in which secondary calcium carbonate occurs in thin plates, and it contains many small calcareous nodules and some small masses that appear to be rolled balls of calcareous mud. Some of the clay is gypsiferous. With the exception of an occasional oyster bed (*Ostrea georgiana*) and a very few fragments of silicified wood the formation contains no fossils. Some of the beds of volcanic ash, notably those at Rio Grande City and at and in the neighborhood of La Loma de la Cruz east of Rio Grande City, at least one of which is 60 feet thick, are in the Frio formation rather than in the Fayette. These ash deposits, however, unlike those in the Fayette, carry no fossil plants; but it should be noted that not all the ash in the Fayette is leaf-bearing.

MIOCENE SERIES.

OAKVILLE SANDSTONE.

Deussen [21] describes and maps in the area covered by him south and west of Brazos River to the border of the lower Rio Grande region a thin formation of white and light-gray quartzitic sandstone, which he calls the Oakville sandstone. This formation is also mentioned by Dumble,[22] Udden,[23] and others. As mapped by Deussen, it lies in a belt a mile wide along the west foot of the Bordas scarp, between the Frio and Reynosa formations, east of Torrecillas, in Webb County, at the north border of the Rio Grande region, but the writer found no certain evidence of the outcrop of this sandstone, although it is doubtless overlapped by the Reynosa, which forms the Bordas scarp. In the lower Rio Grande region the Frio clay seems to continue well up the west slope of the scarp and there to be in contact with the Reynosa formation. Where the Rio Grande has cut across the Bordas, exposing a section, the Reynosa lies directly upon the clay and ash of the Frio formation. Nor does the Oakville appear between these two formations, in the 15 miles of the exposure of their contact in a direction roughly parallel to the dip between Rio Grande City and Sam Fordyce. In roads, pastures, and fields between Randado and the Webb-Zapata shallow oil field and elsewhere along and near the Bordas, to the west, there is a deep white or gray sand which may have been derived from the Oakville. The same kind of sand, however, is commonly found east of the Bordas, where it is derived from the Reynosa formation. It even appears to be derived from the Reynosa west of the Bordas, where there are outliers of the Reynosa.

There are in the region, however, rather thick Miocene sediments, which are overlapped by younger formations. Driller's samples taken at depths ranging from 4,325 to 4,500 feet in the Niels Esperson oil test, 15 miles east of Brownsville, have furnished many invertebrate fossils, of which Dr. Julia Gardner has identified 23 species, all of Miocene age. The exact position of these fossils in the Miocene can not be determined, but according to Dr. Gardner the single fauna represented should probably be assigned to a formation near the top of the lower Miocene or the base of the middle Miocene.

PLIOCENE SERIES.

LAPARA SAND AND LAGARTO CLAY.

The Pliocene Lapara and Lagarto formations, described by Deussen,[24] Dumble,[25] and Udden, Baker, and Böse,[26] from areas farther north, do not outcrop in the Rio Grande region. If they were deposited there they have been covered by the overlapping Reynosa formation.

TERTIARY (?) SYSTEM.

PLIOCENE (?) SERIES.

REYNOSA FORMATION.

Name.—In 1890 Penrose [27] described a deposit of limestone containing many pebbles and cobbles under the name "Reynosa limestone," from the town of Reynosa, Tamaulipas, Mexico. This limestone overlies what was then called the Fayette sand at Reynosa, directly across the Rio Grande from Hidalgo, Tex. Penrose found Recent shells embedded in the surface of exposures of this formation, and thinking it was Recent, included it in his "post-Tertiary formations." In 1891 Hill [28] described remnants of a formation that consisted of coarse and fine gravel cemented by a calcareous matrix and that occupied terraces 400 to 1,000 feet above the Rio Grande to the north of this region. This he called the Uvalde formation. Dumble [29] applied the name Reynosa division to the series of deposits forming the plateau between Nueces and Rio Grande, which he called the Reynosa plateau.

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[21] Deussen, Alexander, Geology of the Coastal Plain region of Texas: U. S. Geol. Survey Prof. Paper 126 (in press).

[22] Dumble, E. T., Problem of the Texas Tertiary sands: Geol. Soc. America Bull., vol. 26, pp. 419 et seq., 1915.

[23] Udden, J. A., Baker, C. L., and Böse, Emil, Review of the geology of Texas: Texas Univ. Bull. 44, p. 97, 1916.

[24] Deussen, Alexander, Geology of the Coastal Plain region of Texas: U. S. Geol. Survey Prof. Paper 126 (in press).

[25] Dumble, E. T., Geology of southwestern Texas: Am. Inst. Min. Eng. Trans., vol. 33, pp. 963-975, 1903.

[26] Udden, J. A., Baker, C. L., and Böse, Emil, op. cit., p. 90.

[27] Penrose, R. A. F., jr., Report of geology for eastern Texas: Texas Geol. Survey First Ann. Rept., pp. 57, 58, 63, 1890

[28] Hill, R. T., Notes on the geology of the Southwest: Am. Geologist, vol. 7, pp. 366-370, 1891.

[29] Dumble, E. T., The Cenozoic deposits of Texas: Jour. Geology, vol. 2, p. 560, 1894.

He stated that the "Reynosa limestone" of Penrose formed the top member of his Reynosa division, which rested on the Lagarto formation. These downstream deposits to which Dumble applied the name Reynosa are now known to be the same as the upstream remnants to which Hill applied the name Uvalde, and the necessity for discarding one of the names has become apparent. In view of the fact that Reynosa as applied to a part of this formation has priority over Uvalde, and that the downstream deposits perhaps afford a better type locality, the name Reynosa has been adopted by the United States Geological Survey and "Uvalde" formation has been abandoned. The outcrop of the formation is continuous from Torrecillas and Rio Grande City eastward. In the area west of the Bordas scarp it occurs as remnantal patches, some of them doubtless reworked. These materials were included by McGee in his "Lafayette," a name no longer recognized as applicable to any geologic formation.

Distribution.—The map shows the distribution of the Reynosa formation in the lower Rio Grande region. Its resistant layers hold up the Frio clay; its base forms the Bordas scarp, from which it dips at a very low angle eastward, outcropping in a north-south belt 40 to 65 miles wide. In much of this area, however, its outcrops are obscured by the wind-blown sands of the sand belt. West of the Bordas it occurs only in patches that occupy the highest elevations.

Relations to adjacent formations.—The Reynosa lies unconformably on all older formations. The dip of the formation is much less than that of the older formations, and as the surface on which it lies is almost flat, it bevels the older formations. This structural unconformity, which is shown on the map, is well seen in the bluffs of the Rio Grande between Rio Grande City and Sam Fordyce. After the deposition of the Oakville, and doubtless after Lapara and Lagarto time, the strata of the region were slightly tilted and a flattish surface was developed across their beveled edges, and on this surface the Reynosa formation was deposited. In this area it is unconformably overlain by the Beaumont clay.

Character.—The Reynosa formation is an intricate mixture of gravel cemented by lime carbonate, uncemented gravel, limestone in which are embedded pebbles and cobbles, almost gravelless limestone, sand, sandstone, gravelly sand, and a relatively small amount of clay.

About 1 per cent of the pieces of gravel are over 4 inches in diameter, and the largest measure 8 inches. About a third of them are of sizes between 1½ inches and 4 inches; another third go through the 1½ inch screen but are caught on the ⅝-inch; and nearly a third goes through the ⅝-inch screen. The patches of gravel near the Rio Grande are a bit coarser than those farther away, and those inland and near the Balcones scarp seem to be somewhat coarser than those away from the river but nearer the Gulf. The gravel includes about 77 per cent of chert, limestone, and vein quartz, materials derivable and doubtless largely derived from the Edwards Plateau, and about 23 per cent of igneous rock, most of them derived from the western Cordillera. Some of the vein quartz may have been derived from points west of the plateau, but on the other hand some of the igneous rocks may have been derived from plugs near the Balcones scarp. Where the gravel overlies the Fayette and Frio formations it includes some silicified wood. Most of the pebbles and cobbles are well shaped by abrasion, many of them are highly polished, and some show bruises made by hard impact during transportation. The gravel deposits are roughly sorted into lenses and pockets of different textural grades.

The limestone is gray and sandy and weathers into rough, irregular surfaces, due to irregular concretions and impurities. In places it has surficially a tufaceous appearance. Its basin, rims, terraces, channels, and concentric banding are suggestive of deposition by springs. The patches south of Espejo ranch, in north-central Webb County, and at Carrizo Springs are clearly spring deposits, but these are not typical, for they contain little or no gravel.

The sand and the sandstone are gray or brown or red and almost universally weather into a dark-red sand. The grains are quartz coated with red iron oxide, but in places where this red coating has been worn off by the wind the sand is gray, or even white.

The few clays are generally sandy, but some are almost fat. Below Rio Grande City the Reynosa formation includes mud balls of Frio clay.

tributaries suggests Pleistocene age rather than Recent. The fact that the streams have degraded their beds as much as 60 feet since the deposits in which the shells are inclosed were laid down also indicates a considerable lapse of time. The deposits are correlated with the Beaumont, which is classified as Pleistocene. The Leona formation is therefore regarded as of Pleistocene age.

RECENT SERIES.

FLUVIATILE DEPOSITS.

Delta deposits are still being formed at the mouth of the Rio Grande. Below Closner, where the normal flood plain merges into the delta, large areas are still subject to flood. What is known as the "Mission ridge," utilized for the railroad, the main automobile road, and the "valley" towns—Mission, McAllen, Pharr, San Juan, and Donna—stands above flood waters and is included within the Beaumont formation, but even here the land slopes away from and toward the river from the axis of the ridge. Other towns in the "valley," including Llano Grande, Mercedes, Harlingen, Raymondville, Lyford, Sebastian, and Brownsville, are likely to be flooded in years of high water, such as 1909, 1919, and 1922. These towns are on higher land, however, and are now largely protected by great irrigation canals and their borrow pits. Breaks occur in the river banks as far upstream as a point above Mission, and old river channels or "resacas" are found on the widening flood plain. These resacas extend down the valley as far as Donna, where they concentrate into the definite channel of the Rio Colorado, which thus becomes a distributary of the Rio Grande. The channel of the Rio Colorado is as much as 40 feet deep where it is deepest, near Harlingen, and 200 feet wide. It carries safely the flood waters of the Rio Grande except at times of the highest floods, when the water breaks through on both sides of Mercedes and flows into the basin of Lake Tiocano and thence northward toward Raymondville, eastward toward the Gulf (crossing the St. Louis, Brownsville & Mexico Railway south of Lyford), and back again southeastward to the Rio Colorado near Harlingen. Much of this water never reaches the Gulf, for the surface is so flat and grassy and the Gulfward slope is so low that the water stands in shallow depressions and behind irrigation canals, and there evaporates or seeps into the porous silts and sands. The area that is subject to flood is mapped as Recent fluviatile deposits. The Rio Grande flood plain above Closner is too narrow to be mapped separately from the Leona terraces and the Tertiary formations where the Leona is missing.

Only the surficial part of this deposit is nonmarine. The area having been reclaimed from the Gulf by the deposition of sediments brought down by the Rio Grande the lower beds are marine, for they contain marine Foraminifera, which are found where the beds are penetrated by wells. The material seen in surface exposures is a mixture of highly calcareous and somewhat selenitic gray, blue, red, and brown clay, checked by joints filled with calcium carbonate, gray micaceous sand, gray silt, and some pebbly sand, the whole impregnated with small white pellets of lime carbonate. The clay greatly predominates.

On the surface of the delta, particularly along the coast from Raymondville to Brownsville, there are numerous mounds, 5 to 30 feet in height, made of clay and known as "clay buttes." Though several diverse suggestions as to the origin of these mounds have been offered, the suggestion made by Coffey,[37] that they are "clay dunes," seems most reasonable. Most of them lie on the leeward side of shallow depressions, which are doubtless the source of the material of which they were formed. Many of these depressions contain salt lagunas.

Fresh-water and land shells, bones, logs, leaves, and other organic matter, all Recent in age, are found in the fluviatile deposits in considerable abundance.

WIND-BLOWN SAND.

Recent deposits that are most widely distributed are the sand dunes and wind-drifted sandy plains of a large area that extends continuously along the coast southward from Baffins Bay to a point east of Raymondville and westward for 75 miles in a belt that is 25 to 50 miles wide from north to south. This area includes practically all of Willacy and Brooks counties and the northern parts of Hidalgo and eastern Jim Hogg counties. Padre Island also consists chiefly of sand dunes blown up from the beach of the Gulfward side of the island. This is an area of migrating and stationary dunes, or "medanos," and of the shallow irregular depressions that are so common in all dune areas.

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[37] Coffey, G. N., Clay dunes: Jour. Geology, vol. 17, pp. 754–755, 1909.

Near the coast, where the Beaumont clay underlies the sand, the depressions contain shallow lagunas, both salt and fresh. There are also considerable stretches of sandy prairie, and at many places where there is no surficial sand the Reynosa and Beaumont formations are exposed. The dunes are sparsely covered with live-oak trees and the prairies are dotted with patches of live-oak brush. There are also large areas of wild grasses and "sacahuista."

Most of the sand is gray or white, but some of it, especially where it overlies the Reynosa formation, is red or pink. It has been thought that all this sand was blown inland from the coast, and perhaps most of it was, although there is no greater source of sand here than elsewhere along the coast, but some of it was derived from the Reynosa formation, on which the sand in the western part of the belt lies. Here "blowholes" expose the Reynosa reddish-brown sands, and the dunes consist of this sand. Even the gray sands may be derived from the Reynosa, the colored iron coating having been abraded from the quartz grains during eolian transportation.

COASTAL DEPOSITS.

Padre Island is a long dune-covered barrier island, which is nowhere more than a mile wide. It incloses Laguna Madre, which is 4 to 10 miles wide. On the Gulf side of the island there are the usual littoral deposits. The beach is sandy and is strewn with innumerable sea shells. The water of the laguna is at most places so shallow that it can be easily waded; indeed, at some times and places it is only a mud flat incrusted with precipitated salts. At Point Isabel, however, gasoline launches ply between the mainland and the island, but long piers are necessary, and the boats drag the bottom for considerable distances out from either shore. In the laguna mud, silt, sand, shells and fragments of shells, and salt are all being laid down to form the usual lagoon deposit.

IGNEOUS ROCKS.

In southwestern Uvalde County, just outside the region and not shown on the map, there are several small exposures of igneous rocks in the form of plugs or necks. Most of them make hills, but some are exposed in stream valleys or on flat surfaces. The rocks are phonolites and basalts, which have been described by Cross.[38]

STRUCTURE.

The general dip of the strata in the Rio Grande region is eastward. North of Laredo the dip is south of east, between Laredo and San Ygnacio it is nearly due east, and below San Ygnacio it is north of east.

The averages of the dips read for the formations are shown below.

Average dip, in feet per mile, of formations in the Rio Grande region.

Beaumont clay (Pleistocene)	25
Reynosa formation (Pliocene?)	17
Frio clay	263
Fayette sandstone	201
Yegua formation	296
Cook Mountain formation	435
Mount Selman formation	180
Wilcox group (Bigford formation, Carrizo sandstone, and Indio formation)	384
Midway formation	155

These averages are probably too high, however, for the steeper dips are those that are most commonly read. At most places the strata are so nearly horizontal that the dip is not observable. The true average dip of each formation is probably less than half that given above. According to the figures given the average dip of the Eocene formations is 273 feet per mile and the Reynosa and Beaumont together average 21 feet per mile. These figures should probably be reduced to 136 and 10, respectively, or even to lower figures. The discrepancy between the Eocene and post-Eocene formations again emphasizes the structural unconformity at the base of the Reynosa.

The reconnaissance methods employed did not permit detailed structural investigations, but indications of abnormal structure were observed or were authentically reported to occur at a few places. According to Baker[39] there is an anticline about 10 miles west of Carrizo Springs, another about 15 miles southeast of Eagle Pass, and probably still another, lying chiefly in Mexico, southwest of the old Indio ranch house. The writer saw indications of the first of these. The second is described by Udden.[40] Along Nueces River below Pulliam, there are anticlines and synclines and faults of small throw. The eastward dip is somewhat accentuated at the Webb-Zapata shallow oil field, in the southeast corner of Zapata County. There are relatively steep reversed dips in the vicinity of Roma. Probably an anticline here crosses the international boundary. A large anticline has been mapped by Crider[41] east of Laredo. Normal faults of small displacement were observed on Chaparrosa Creek 11 miles west of La Pryor, and half a mile east of the Jones ranch, northwest of Crystal City.

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[38] Cross, Whitman, U. S. Geol. Survey Geol. Atlas, Uvalde folio (No. 64), pp. 3, 4, 1900.

[39] Baker, C. L., personal communication.

[40] Udden, J. A., Report on a geological survey of the lands belonging to the New York & Texas Land Co.: Augustana Library Pub. 6, pp. 88-90, 1907.

The search for structural features in the Rio Grande region is full of difficulties and subject to inaccuracies, for formations vary in character from place to place, the beds occur in lenses and pockets, the formational contacts are ill defined, exposures are scarce, wells are few, and the logs of most of those which have been drilled are inadequate, and false bedding planes, which dip at all angles with reference to the true bedding, are abundant.

There is at least one salt dome in the region. It is about 5 miles southeast of Falfurrias and crosses the Beaumont-Reynosa contact. It is 5 miles long from east to west and 1 to 1½ miles wide from north to south. Quaquaversal dips are not plainly seen, but a surrounding laguna of salt brine, a large body of gypsum on the southwest side, and a topographic swell that is more than 40 feet high indicate that there is a salt dome at this place. La Lomita (little hill), 6½ miles south of Mission, on the Rio Grande, which stands conspicuously above its alluvial surroundings and exposes abnormal materials and abnormal dips may also be a salt dome, but the dips may not represent true bedding planes.

ECONOMIC GEOLOGY.

OIL AND GAS.

More than 45 separate projects are under way for the development of oil and gas in the region, but only three are producing. The locations of these projects are shown on the map (Pl. XXVIII).

In 1920 the Webb-Zapata Co. had drilled 45 wells in the southeast corner of Zapata County to an average depth of 160 feet and found some oil and a very little gas in the Fayette sandstone. The dip here is normal in direction, a few degrees south of east, and is 198 feet per mile, somewhat more than the general dip in the neighborhood. As there are no reversed dips, the oil probably occurs in a lens of sand, which plays out and is sealed up westward, for the cap rock crops out 1¾ miles west of the west border of the producing area. Eight of the wells were pumping in 1920, a gasoline engine on each. The average yield is between 3 and 4 barrels a day. As the field is more than 40 miles from the railroad at Hebbronville, and as the road is very sandy, all attempts to market the oil had failed up to the time of the writer's last visit. The oil was stored in steel tanks at the field. According to recent reports it is being marketed.

Another producing field is 25 miles south of Aguilares and 45 miles southeast of Laredo, in Zapata County. Gas only is produced. The field is developed and operated by the Border Gas Co., of Laredo. The gas is conducted through pipes to Laredo, where the company operates the city gas plant. The outcropping formation at the wells is Fayette. A little gas is obtained from a depth of 700 feet, but the main flow is obtained from a depth of 1,200 to 1,250 feet. The material penetrated in all the wells is almost entirely clay but includes thin seams of sandstone. The main gas sand lies in the basal part of the Yegua or the upper part of the Cook Mountain. The structure here also is homoclinal, the gas sand dipping eastward at the rate of 30 feet to the mile.

In the spring of 1921 oil was struck in a well of the Mirando Oil Co., in the extreme northeast corner of Zapata County. The well site is just west of the Reynosa-Frio contact, and practically the full thickness of the Frio clay is represented under it. The oil sand was struck at 1,430 feet from the surface, in the Cook Mountain formation. The first well is variously reported as having given an initial production of 20 to 100 barrels a day. The new field has been rapidly developed. In the spring of 1922 it was credited with 13 producing wells, and the estimated possible production ranged from 1,000 to 2,300 barrels a day.[42] In addition, more than a score of other wells were being drilled in other parts of Zapata and Webb counties.

This field has produced also considerable gas. The Caroline-Texas Co.'s test well near Bruni is reported as blowing 8,000,000 to 10,000,000

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[41] Crider, A. F., personal communication.

[42] McGreal, P. L., Gulf coast oil operations: Oil and Gas Jour., vol. 20, No. 43, p. 18, March 24, 1922.

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cubic feet and the Laurel Oil Co.'s well No. 1, at Mirando, as blowing 40,000,000 cubic feet. According to Lupton[43] the Aviator well, which is about halfway between Mirando and the Mirando City pools, was brought in with an estimated production of 40,000,000 cubic feet in June, 1922. Well No. 2 of the Schott Oil Co. is also a gasser.

As the first well was not completed when the writer was last in the field the structure in the Mirando district has not been worked out. Wrather,[44] however, states that the producing sands in the Mirando and the Jennings fields are at approximately the same horizon.

The future of the Mirando field can not yet be confidently predicted, but the field will probably be thoroughly tested by the end of 1922.

Gas has been found at several other places, notably at Reiser, 2½ miles west of Aguilares, in Webb County; in the Spurrier wells Nos. 1 and 3, in western Starr County; in the Higgins Oil & Gas Co.'s wells, 15 miles southeast of Eagle Pass, in Maverick County; and in the well of the International Refining Co., 7 miles northeast of La Pryor, in Zavalla County. At Reiser, which is only a few miles northwest of the northern border of the Mirando field, the gas is obtained from the Yegua and Cook Mountain formations at depths ranging from 150 to 1,650 feet. The Spurrier wells also contain gas, though in small quantities, from the Yegua. The gas in the Higgins wells is obtained from Cretaceous beds. The well of the International Refining Co. is reported to have struck a 50,000,000 cubic foot gas blow at a depth of 1,200 feet from the surface. The outcropping formation is the Indio, and presumably this gas also comes from Cretaceous beds. The first well at Pulliam, on the Uvalde-Zavalla county line, is reported to have produced about 5 barrels of oil a day.

So far as known the results of all other tests have been negative. However, outside of the Mirando field few of the deep test wells have been completed, and oil may have been struck in wells unknown to the writer. Several of the projects, notably those of the Higgins, International, and Empire companies and the Hanchett project, have been carried on in a serious and intelligent manner, but the operators drilling many of the wells have shown neither intelligence nor diligence.

The search for oil and gas in paying quantities will be continued only with great difficulty and with large risk of money. The work of locating and mapping areas in which the structure is favorable is difficult, and even a well-developed and accurately mapped anticline may contain no oil-bearing sand. The possibility that the San Miguel formation (correlated with part of the Taylor marl and the Anacacho limestone) of the Upper Cretaceous, may be petroliferous is not unpromising. The Cook Mountain formation gives some indication of being a fairly persistent producing sand where the structure is favorable. Both oil and gas have been found in this formation in the Mirando field and in smaller quantities elsewhere. It appears to contain indigenous petroleum at Oil City, Nacogdoches County, and at Crowther, McMullen County. This formation should be tested wherever drilling is done. The expenses of development will be high, for a large part of the region is not easily accessible to railroads or seaports, and even after development there is still the problem of getting the product to market.

Probably the most promising structural features to look for and to test are salt domes. About 50 per cent of the known Texas salt domes have produced oil and some of them have produced it in large quantities. The salt dome southeast of Falfurrias was tested some years ago by the Texas Co., but with negative results. The hill south of Mission, known as La Lomita, which may be a salt dome, is now being tested by the La Lomita Oil Syndicate. Other salt domes will doubtless be discovered in the region, and petroleum may be found in them.

On the whole the prospects of the ultimate discovery of one or more highly productive oil or gas fields in this region are not discouraging, but the preliminary work should be done with great care and the money required will be expended at considerable risk.

COAL.

According to Ashley,[45] the coal which has been extensively mined at Minero, Dolores, Cannel, and Santo Tomas, in Webb County, and which is in the Mount Selman formation, is probably the largest body of cannel coal of bituminous rank in the United States, if not in the world. Johnson & Coleman are taking out enough of this coal at their mine, 4 miles east of Palafox, to run their pumping plants on the river. Coal from the same formation, and probably of about the same quality, is found on Espada Creek, in Webb County, near the base of the Mount Selman formation. A 14-inch bed of coal is also reported to outcrop near the top of the Mount Selman formation on the Rio Grande at low water at and near the mouth of Arroyo Santa Isabella.

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[43] Lupton, C. T., oral communication to L. W. Stephenson.

[44] Wrather, W. E., The Mirando Oil Co. well, Zapata County, Tex.: Am. Assoc. Petroleum Geologists Bull., vol. 5, p. 625, 1921.

[45] Ashley, G. H., The Santo Tomas cannel coal: U. S. Geol. Survey Bull. 691, pp. 251-270, 1919.

Beds of coal, probably of poorer quality, may be obtained from the Indio and Bigford formations at many places where these formations outcrop. Lignite is found at the surface and at shallow depths at places east and southeast of Dentonio and at the Mangrum and Rutledge ranches, west and south of La Pryor. It is also penetrated in wells at La Pryor. An 18 to 20 inch bed of hard, brittle, and bright coal outcrops 1½ miles above the mouth of San Lorenzo Creek, in Webb County, in the Bigford formation. There is also an exposure of coal at the mouth of the first creek south of the Apache ranch house.

At Pilotes ranch, about 10 miles north of Palafox, as many as 11 seams of coal and bone were struck in a test drilling at depths ranging from 74 to 236 feet. The surface formation here is the Mount Selman, but the carbonaceous beds are in the Bigford formation. Coal in this same formation outcrops on Concillos Creek near its mouth and on Nueces River 2¾ miles east of the Asherton-Big Wells road, a few miles outside the Rio Grande region.

Coal is reported by Judge A. F. Spohn, of Zapata, to occur just north of Zapata and in the valley of Dolores Creek near the Webb-Zapata county line. This locality is in the outcrop of the Cook Mountain formation. No coal was seen, however, in the many sections of the Cook Mountain formation examined.

WATER RESOURCES.

Deussen and Dole[46] have investigated the underground water resources of La Salle and McMullen counties, and Deussen[47] has reported
on the underground waters of the whole of
southern part of the Texas Coastal Plain.
counties mentioned are close to the lower
Grande region and the conditions that pre
in them extend into this region.

BRICK-MAKING MATERIAL.

Few of the clays of the lower Rio Gra
region are suitable for making good br
There is an abandoned brick plant at Re
The pit is in uppermost Yegua or lo
Fayette, and the clay is fairly pure. Fa
brick of good grade was made here. The p
was abandoned when the Border Gas
shut down its gas wells at Reiser, thus s
ting off the gas used as fuel. At no o
place in the region has facing brick been m
factured.

Along the lower Rio Grande and its n
delta distributaries there are numerous
from which material is taken by Mexicans
making crude adobe brick. The largest
most efficient plant of this kind is at
Ebanos, about 2 miles southwest of
Fordyce. Beaumont terrace silts, or re
fluvial silts, are mixed with water in the pit
worked into plastic masses having the
sistency of dough. This material is thr
into trays containing six brick-sized comp
ments, which are sprinkled with dry san
prevent it from sticking. The clay-filled
is then carried by hand to a sunny flat near
pit and inverted, the wet bricks being left f
time to dry. When they have dried out s
ciently they are stacked or "ricked" in o
piles for further drying by sun and w
Finally they are placed in rough kilns mad
adobe bricks and baked, branches of
quite being used as fuel. The brick is p
but it stands fairly well the pressure of
common Mexican one-story house.

GRAVEL.

The gravel supplies of the region are ple
ful, widely distributed, and of good qual
The Reynosa formation furnishes gravel
high grade for road ballast and concrete
practically wherever it is exposed, whethe
the main outcrop of the formation or wes
the Bordas scarp, where only patches of

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[46] Deussen, Alexander, and Dole, R. B., Ground water in La Salle and McMullen counties, Tex.: U. S. Geol. Survey Water-Supply Paper 375, pp. 141-177, 1916.

[47] Deussen, Alexander, Geology and underground waters of the
eastern part of the Texas Coastal Plain: U. S. Geol. Survey
Supply Paper 335, 1914; Geology of the Coastal Plain region of
U. S. Geol. Survey Prof. Paper 126 (in press).

nosa are found. As only 1 per cent of the gravel is over 4 inches in diameter, as three-fourths of the pebbles and cobbles are composed of chert or other siliceous material, as the pieces are well rounded and smooth, and as the material is practically nowhere so firmly cemented as to require blasting in its excavation, this deposit makes excellent commercial gravel. There are half a dozen or more pits along the river between Sam Fordyce and Peñitas. In some the loosely cemented and unconsolidated gravel is taken out with steam shovels, and in others it is removed by hand. At some plants it is sorted by power-driven screens, and at others by hand screening. Most of the gravel is used in the valley, but some is shipped as far as Houston. At Green's, in Webb County, on the International & Great Northern Railway, where there is an outlier of Reynosa, a large pit has long been under excavation. Most of the gravel is loaded by steam shovels into cars and used as ballast on the railroad. Some of it has been used to surface a section of the San Antonio-Laredo wagon and automobile road between Green's and Webb.

SAND.

Good sand is not so abundantly produced as gravel, although there is plenty of it. The sand lenses in the Reynosa would furnish some, but they do so only where the sand is mixed with the finest grades of gravel. The sand sorted out of the Reynosa by the wind and piled into dunes in the main sand belt and elsewhere is generally pure, fine-grained quartz sand, but it is not used commercially. An abundance of sand is derived from the coastal beaches and lagoons in the sand belt also, but neither is this produced. The only sand used commercially to-day is in the Beaumont delta-like deposits at Mission and McAllen, where 25-foot lenses of almost pure-white sand, underlie clay and silt. The sand obtained at Mission sells for $2.25 a cubic yard at the pit.

GYPSUM.

The sediments of the region inclose a large amount of gypsum in thin beds, seams, plates, crystal aggregates, and larger bodies, but it is nowhere utilized.

ROAD MATERIAL.

The quartzites, sandstones, limestones, concretions, and conglomerates of the region would make good material for building roads, but as few roads have been built they have not yet been so utilized. Argillaceous and calcareous materials from the Reynosa formation have been used to harden an excellent road through the sand belt from Falfurrias to Edinburg, permitting automobile traffic into the valley from coastal points farther north.

Shallow pits are opened along the road every mile or two and the material is laid on a graded surface of sand. This road lacked about 10 miles of being completed in 1920. The same material is being used in the same way on the sandy road to Rio Grande City from Hebbronville.

CEMENT.

It is possible that a proper combination of limestone, clay or shale, and gypsum might be found for the manufacture of Portland cement, coal, oil, or gas being used for fuel, but no commercial concern has yet found this combination.

NEW SPECIES OF MOLLUSCA FROM THE EOCENE DEPOSITS OF SOUTHWESTERN TEXAS.

By JULIA GARDNER.

The new species and subspecies whose names are used in the preceding paper by A. C. Trowbridge are described below. One species that had already been described and that is here treated as a subspecies of *Ostrea alabamiensis* is considered in detail because of its abundance in the middle and upper Eocene deposits in the lower Rio Grande region.

The letters after some of the station numbers have the following significance: (a) abundant, (c) common, (p) present, (r) rare.

PELECYPODA.

Family NUCULIDAE.

Genus NUCULA Lamarck.

Nucula sp.

Plate XXIX, figure 3.

The rock in the area a little south of Laredo, in Webb County, is made up largely of a *Nucula*, which is probably distinct from any species described, though it is very close to *N. magnifica* Conrad. It is about 3 centimeters high and broad and is sculptured with prominent growth lines and a uniformly developed, subcutaneous radial threading. No hinges or perfect exteriors have been found, but the pearly fragments of the thick shell pack the matrix.

Occurrence: Cook Mountain formation. Station 7492 (p), 1 mile east of Laredo; station 8818 (a), 5 miles southeast of Laredo, Webb County.

Family OSTREIDAE.

Genus OSTREA (Linnaeus) Lamarck.

Ostrea tasex Gardner, n. sp.

Plate XXXI.

?*Ostrea multilirata* Conrad, U. S. and Mex. Boundary Survey Rept., vol. 1, pt. 2, p. 157, pl. 12, figs. 1 a–d, 1857.

Shell of only moderate dimensions for the genus, subequivalve, ovate-trigonal in outline, generally somewhat produced anteriorly; surface layer decorticated; both the right and left valves radiately sculptured with 15 to 20 fine, approximately uniform, rippling riblets, similar to those developed upon the attached valve of *O. crenulimarginata* Gabb; ligament area moderately large, somewhat flattened in the right valve, the medial depression relatively wide, broadly but not deeply excavated; growth striae obvious; lateral margins very finely crenate, the crenae persistent in some individuals around the entire inner margin; basal margin often fluted in harmony with the external sculpture; adductor muscle scar crescentic, lying below the median horizontal, moderately large, not very deeply excavated; pedal scar obscure.

Dimensions: Right valve, altitude 80 millimeters, latitude 65 millimeters; left valve, altitude 98 millimeters, latitude 72 millimeters.

Type locality: Station 8925, a quarter of a mile northeast of Glass ranch headquarters, Dimmit County, Tex.

Ostrea tasex is the analogue in southwestern Texas of *Ostrea crenulimarginata* of the Midway of Alabama. In the Alabama species, however, the right valve is smooth, but in those found along the Rio Grande the two valves are similarly sculptured. Toward the umbones the radials are sharply elevated, though they tone down into an even fluting toward the outer margin.

Ostrea tasex is probably identical with *Ostrea multilirata* Conrad, collected from the so-called Cretaceous of "Dry Creek, Mexico." Conrad's types are in the National Museum and are fairly well preserved. Nothing of the kind has been reported from the Cretaceous by later investigators who have collected extensively in the Rio Grande area. However, *Ostrea cortex*, collected at the same locality, is certainly a Cretaceous species, and until "Dry Creek" can be definitely located and the confusion in the stratigraphic relations cleared the Wilcox form may well be kept apart.

Stations in Indio formation.

8927 (c). 4 miles south of Rockdale, Milam County.

6278 (a). 11 miles south of Sabinal, Uvalde County.

3187 (r?). East side of the Rio Grande, in Maverick County, about 3½ miles above the mouth of San Ambrosia Creek.

9173 (c). 17 miles west of Carrizo Springs, Dimmit County.

8925 (c). A quarter of a mile northeast of Glass ranch headquarters, Dimmit County.

1/67 (c). 3 miles north by west of San Pedro ranch, on the Maverick-Dimmit County line.

Ostrea alabamiensis subsp. georgiana Conrad.

Plate XXIX, figures 6, 7; Plate XXX.

Ostrea georgiana Conrad, Acad. Nat. Sci. Philadelphia Jour., 1st ser., vol. 7, p. 156, 1834.

Dana, Manual of geology, 1st ed., p. 519, fig. 811, 1863.

Dall, Wagner Free Inst. Sci. Trans., vol. 3, pt. 4, p. 683, 1895.

Ostrea titan Conrad, Acad. Nat. Sci. Philadelphia Proc., 1st ser., vol. 6, p. 199, 1854; Pacific R. R. Rept., vol. 6, pt. 2, p. 72, pl. 4, fig. 17a; pl. 5, fig. 17a, 1857.

Ostrea contracta Conrad, U. S. and Mex. Boundary Survey Rept., vol. 1, pt. 2, p. 160, pl. 18, fig. 1 a–d, 1857.

Ostrea alabamiensis Conrad var. *contracta* Harris, Bull. Am. Paleontology, vol. 6, p. 9, pls. 3, 4, pl. 5, fig. 2, 1919.

Type localities: "Orangeburgh, S. C.; Shell Bluff and near Milledgeville, Ga."—Conrad, 1834.

Ostrea alabamiensis subsp. *georgiana* is the most conspicuous species in the later Eocene of Texas, and in many localities it is the only fossil collected. Its range of variation, like that of other oysters, is wide. Only a very small percentage of individuals retain the fine epidermal sculpture, the one constant feature, and one identical with that of *O. alabamiensis*. However, in the large mass of material available for study—several hundred individuals—certain differences in the average individual developed at the different horizons can be detected. None of the huge, very much elongated and massive shells so common in the Fayette near Roma in Starr County have been found in the Cook Mountain formation farther north. The forms occurring at this lower horizon are of only moderate dimensions, usually relatively thin and broadening at the base, and, as a rule, conspicuously laminar. This decided laminosity is one of the more persistent features of the Cook Mountain *O. georgiana*. The Cook Mountain form grades into *O. alabamiensis* though the hinge is usually heavier and more elongated. The very large, massive, narrow, and elongate individuals described by Conrad under *O. contracta* occur in considerable numbers in the Yegua, and in the Fayette this type has shut out almost entirely the smaller and thinner race of the Cook Mountain.

Stations in Cook Mountain formation.

6650 (c), 6657 (c), 6652 (c). Environs of Cotulla, La Salle County.

8816 (p). 100 feet south of windmill, Marguerita ranch, 6.4 miles west of Webb Station, Webb County.

8785 (p). 2.1 miles east of Webb, Webb County.

8841 (p). Half a mile west of triangulation station Dolores, 2 miles north of Dolores, Webb County.

8842 (p). Three-fourths mile west of triangulation station Dolores, Webb County.

8830 (p). 10 miles northwest of Laredo, Webb County.

2113 (c). 5 miles northeast of Laredo, Webb County.

8765 (r). 2.3 miles northeast of Laredo, at crossing of San Antonio road with International & Great Northern Railway, Webb County.

7492 (p). 1 mile east of Laredo, Webb County.

6058 (c) (old series). Laredo, Webb County.

8835 (a). 6 miles southeast of Laredo, Webb County.

6436 (r). La Perla ranch, below Laredo, Webb County.

8840 (c). North bank of Salado Creek, Zapata County.

9116 (c). Soledad, Zapata County.

9112 (c). 2 miles down the river from Zapata, Zapata County.

9109 (p). Rio Grande prospect, 4.8 miles southeast of Zapata, on Roma road, 2.5 miles northeast of main road, Zapata County

9110 (p). 4.8 miles southeast of Zapata, Zapata County.

9113 (c). 5½ miles southeast of Zapata, Zapata County.

9175 (p). 14.2 miles below Zapata, Zapata County.

6432 (r). Arroyo Dolores, Zapata County.

9106 (r). Zapata County.

Stations in Yegua formation.

8784 (a). 3.4 miles east of Cactus Station, Webb County.

8809 (c). 12 miles northeast of Laredo, Webb County.

8849 (p). 7 miles northeast of Laredo, Webb County.

8061 (c). 7 miles east of Laredo, Webb County.

8834 (a). 8 miles east of Laredo, Webb County.

9119 (p). 2½ miles southwest of Alejandreñas ranch, Zapata County.

7741 (r). 1 mile northwest of Pedernal ranch headquarters, Zapata County.

9182 (a). 3.2 miles northeast of Lopeño, Zapata County.

8843 (a). 23½ miles northwest of Rio Grande City, Zapata County.

9187 (p). 2¾ miles south of Romireño, Zapata County.

9188 (p). 3 miles south of Romireño, Zapata County.

Stations in Fayette sandstone.

6147 (a). C. T. Tom ranch, ¾ mile south of Campbellton, Atascosa County.

6144 (a) 6 miles east of Campbellton, Atascosa County.

6146 (p). 3 miles southeast of Campbellton, Atascosa County.

3601 (r). Winchester, Fayette County.

9094 (p). Reiser, Webb County.

9098 (c). 1.3 miles southwest of Webb-Zapata shallow oil field, Zapata County.

7740 (a). Charco Redondo ranch, Zapata County.

8060 (p). Charco Redondo ranch, Zapata County.

9179 (p). 3.6 miles northeast of Palo Blanco ranch, Zapata County.

9181 (a). 3 miles northeast of La Presa ranch house, Zapata County.

9096 (c). 3.6 miles south of Huisatche ranch, Jim Hogg County.

9192 (p). 19 miles north of Roma, Starr County.

9191 (c). 15 miles north of Roma, Starr County.

9189 (r). 7 miles above Roma, Starr County.

9193 (c). 1.7 miles northeast of Agua Dulce ranch, north of Roma, Starr County.

7493 (p). 12½ miles below Arroyo Tigre on road to Roma, Starr County.

Stations in Frio clay.

6666 (r). 9 miles north of Tilden, McMullen County.

6665 (a). One-fourth mile east of post No. 7, west of Tilden, McMullen County.

3093 (p). Fort Ringgold, Starr County.

Family PARALLELODONTIDAE.

Genus CUCULLAEA Lamarck.

Cucullaea is one of the more conspicuous fossils in the Midway of Texas. Apparently there is but a single species, though the small and poorly preserved northern forms may prove to be distinct from those of the Rio Grande province. This species is certainly not identical with *C. macrodonta*, found farther east, though the differences may not be of specific rank. Its relation to *C. saffordi* Gabb, described from a lost type two-tenths of an inch in latitude, is even less definite.

Cucullaea (macrodonta subsp.?) texana Gardner, n. subsp.

Plate XXIX, figures 4, 5.

Cucullaea macrodonta Harris (part), Bull. Am. Paleontology, vol. 1, No. 4, p. 165, 1896.

Cucullaea saffordi Harris (part), Bull. Am. Paleontology, vol. 1, No. 4, p. 165, 1896.

Shell large, heavy, inflated, the single valves rudely quadrate in outline, the double valves cordate in cross section through the umbones; umbones prominent, inflated, overhanging the cardinal area, the tips incurved and prosogyrate, slightly in advance of the median vertical; length of hinge approximately five-sixths that of the shell; anterior extremity angulated dorsally, rounding broadly into the ventral margin; base line approximately horizontal medially; posterior extremity obliquely truncate; posterior area flattened, delimited by a narrow but obtuse ridge with a shallow sulcus behind it; valves differentially sculptured, the right valve exhibiting about 30 low, broad radials separated by linear interspaces and persisting to the posterior keel, where they abruptly disappear; a very fine, close, and uniform radial cording developed upon the posterior area in some individuals, but commonly absent, as in the type, or evanescent toward the margin. Left valve exhibiting only about 24 radials distributed over the medial and anterior portions of the shell but absent upon the posterior third, narrower than those upon the right valve and separated by interspaces of a width almost equal to the radials; sculpture of posterior area similar in the two valves; incremental sculpture pronounced, particularly toward the base; hinge area of moderate width for the genus, obliquely grooved; hinge very imperfectly preserved; very narrow medially with short vertical teeth, abruptly widening near the extremities; distal teeth coarse, few in number, and rudely parallel to the hinge margin; characters of interior not known.

Dimensions: Altitude, 42.0 millimeters; length of hinge, 39.0 millimeters; maximum latitude, 47.5 millimeters; diameter, 40.0 ± millimeters.

Type locality: White Bluff, Rio Grande, Maverick County, Tex. Type, U. S. National Museum.

The specimens from Kaufman County, in the northern part of the State, are smaller than those from points along the Rio Grande. They differ, too, in the more uniform development of a radial sculpture upon the posterior area.

Cucullaea (*macrodonta* subsp. ?) *texana* varies widely in outline and to a lesser degree in detail of sculpture. The shell runs larger and heavier than the typical *C. macrodonta* Whitfield, and the sculpture of the left valve, though discrepant, is regular and differs from that of the right only in the narrower ribs, wider interspaces, and in its development over a more restricted portion of the shell. These differences, though slight, are fairly constant in the imperfect material in hand. *Cucullaea saffordi* Gabb was described from a shell 0.2 inch in latitude. This type, according to Harris, has been lost. Until the young have been correlated with adults at the type locality and the species adequately described from such material the characters of *C. saffordi* Gabb must be open to question. There is need for uncommon caution in Hardeman County, as the Upper Cretaceous and Eocene outcrops are very near to one another and were confused in some of the earlier collections.

Stations in Midway formation.

2440 (c). 4 miles east of Kemp, Kaufman County.

2439 (r). 1 mile east of Webberville, Travis County.

?6584 (r). D'Hanis-Yancey road, about 7½ miles east of south of D'Hanis, Medina County.

3180 (c). Bluff on Frio River, half a mile below Myrick's (Evans's) apiary, Uvalde County.

583 (r). 18 miles southeast of Eagle Pass, Maverick County.

4398 (p). 18 miles southeast of Eagle Pass, Maverick County.

6583 (p). Biboro Creek, just below Biboro tank, about 18 miles southeast of Eagle Pass, Maverick County.

6575 (c). White Bluff on Rio Grande, land of Indio Cattle Co., about 4½ miles west of south of Jacal ranch house, in southeastern part of Maverick County.

Family CARDITIDAE.

Genus VENERICARDIA Lamarck.

Venericardia (alticostata subsp.?) whitei Gardner, n. subsp.

Plate XXXII, figure 3.

Venericardia alticostata Harris (part), Bull. Am. Paleontology, vol. 1, No. 4, p. 171, pl. 5, fig. 3, 1896.

Not *Venericardia perantiqua* Conrad, Am. Jour. Conchology, vol. 1, p. 8, 1865.

Shell small but thick and heavy, tranversely elongated in outline, rather compressed; umbones low, broadly rounded, for the most part strongly anterior in position; lunule minute; anterior extremity bowed in front of the lunule; posterior extremity obliquely produced and broadly rounded; base line feebly arcuate; surface coarsely sculptured radially; radials usually 19 to 21 in number, broad, crowded and heavily corrugated upon the anterior and medial portions of the shell; narrow and less closely spaced posteriorly; ligament characters not known; dentition apparently normal, very poorly preserved in all the material available for study; adductor scars very distinct; pallial line simple; inner margins very coarsely crenate.

Dimensions: Altitude, 25 millimeters; latitude, 31 millimeters; semidiameter, 13.5 millimeters.

Type locality: Station 3180, Bluff on Frio River half a mile below Myrick's apiary, Uvalde County.

The new subspecies differs from *V. alticostata* s. s. and from the subspecies *hesperia* in the simple radials. *V. smithii* is larger and relatively higher as a rule, with normally over 30 radials instead of less than 25, as in *whitei*.

Venericardia perantiqua was described under the name *Cardita subquadrata* by Gabb from the Eocene of New Jersey. The casts are very imperfect, but they indicate a much compressed, trigonal to subquadrate form quite unlike anything reported from the Eocene of Texas or of the Gulf.

The form is named in honor of Dr. Charles A. White, one of the foremost of the earlier paleontologists and one of the first to collect from the Texas Tertiary formations.

Stations in Midway formation.

3180 (p). Bluff on Frio River half a mile below Myrick's (Evans's) apiary, Uvalde County.

6279 (r). 11 miles south of Sabinal, a few hundred yards south of the junction of Elm Creek with Sabinal Creek, Uvalde County.

4398 (r). 18 miles southeast of Eagle Pass, Maverick County.

Venericardia alticostata subsp. hesperia Gardner, n. subsp.

Plate XXXII, figures 1, 2.

Venericardia alticostata Harris (part), Bull. Am. Paleontology, vol. 1, No. 4, p. 171, 1896.

Not *Cardita alticostata* Conrad, Am. Jour. Sci., 1st ser., vol. 23, p. 342, 1833.

Shell of moderate dimensions, thick, porcellanous, inflated-cordate in cross section; umbones prominent, well rounded, slightly anterior in position; lunule very small, deep; anterior extremity strongly and evenly bowed in front of the lunule; posterior dorsal margin gently sloping, the posterior lateral margin obliquely truncate; base line feebly arcuate, strongly upcurved anteriorly, abruptly rounded posteriorly; general character of surface sculpture similar to that of *V. alticostata* s. s.; radials not far from 20 in number, normally tripartite on the anterior and medial portions of the shell as in *V. alticostata;* crest of radials narrow and sharply serrate; lateral "terraces" well defined; inter-radial channels broadly U-shaped; incremental sculpture very fine and sharp; heavy growth stages rarely developed; hinge and ligament characters poorly preserved; hinge plate thick, heavy; adductor scars impressed, the anterior excavated; pallial line simple; inner margins deeply crenate.

Dimensions: Altitude, 38 millimeters; latitude, 37 millimeters; diameter, 44 millimeters.

Type locality: Station 3180, Bluff on Frio River half a mile below Myrick's apiary, Uvalde County.

The subspecies *hesperia* is shorter and wider than *V. alticostata* and more inflated in the umbonal region. In sculptural characters, however, the two forms are similar.

Venericardia bulla Dall is smaller and relatively higher and has a higher and relatively heavier hinge plate and less numerous radials. In both *V. smithii* Aldrich and *V. alticostata* subsp. *whitei* the radials are simple.

Stations in Midway formation.

1128 (p). 1¾ miles northwest of New Fountain, Medina County.

3180 (p). Bluff on Frio River half a mile below Myrick's (Evans's) apiary, Uvalde County.

3181 (p). Frio River just above waterhole opposite apiary, below Englemann's ranch, Uvalde County.

?6279 (r) (No. 274c). 11 miles south of Sabinal, a few hundred yards south of the junction of Elm Creek with Sabinal Creek, Uvalde County.

?4398 (r). 18 miles southeast of Eagle Pass, Maverick County.

6583 (p). Biboro Creek, just below Biboro tank, about 18 miles southeast of Eagle Pass, Maverick County.

6575 (p). White Bluff on Rio Grande, land of Indio Cattle Co., about 4½ miles west of south of Jacal ranch house, in the southeastern part of Maverick County.

Family VENERIDAE.

Genus CALLOCARDIA.

Callocardia astartoides Gardner, n. sp.

Plate XXXII, figures 4-7.

Shell small for the genus, thick shelled, trigonal, ovate in outline, astartiform, moderately compressed; umbones not conspicuous, the tips proximate and prosogyrate, slightly anterior; lunule rather wide, cordate, slightly depressed, and delineated by an incised line; escutcheon not defined; anterior extremity bowed slightly in front of the lunule; posterior end of shell obliquely truncate and feebly arcuate from the umbones to the basal margin; base line arcuate, more abruptly rounded posteriorly than anteriorly; external surface finely and evenly threaded concentrically; resting stages conspicuous, usually one strongly defined near the umbones and several not quite so prominent toward the base; a fine and regular radial lineation visible upon weathered surfaces; external ligament mounted upon a rather heavy nymph produced more than one-third of the length of the posterior dorsal margin; dentition robust; the laminar anterior cardinal of the right valve broken away; medial cardinal rather slender, cuneate; posterior cardinal produced; left anterior and medial cardinals united under the umbones to form an asymmetric V, the anterior cardinal slender, the medial cardinal relatively heavy and deltoid; posterior left cardinal broken away, doubtless very thin and laminar; a very short obtuse lateral tooth developed in the left valve, received in a corresponding socket in the right; adductor scars distinct, the anterior the more prominent; pallial sinus produced almost to the median vertical, obtusely trigonal; inner margins entire.

Dimensions: Right valve, altitude 16.0 millimeters, latitude 16.5 millimeters, semidiameter 7.4 millimeters; left valve, altitude 17.0 millimeters, latitude 17.3 millimeters, semidiameter 8.6 millimeters.

Type locality: Station 8833, about 7 miles up the Rio Grande from Laredo, at Knob Bluffs, a quarter of a mile above pump of Santa Barbara farm, Webb County, Tex.

Callocardia astartoides is a remarkable species, uniting the dentition and sinal characters of the Veneridae with the external outline and surface sculpture of certain of the Astartidae. The occurrence of so primitive a type of a highly specialized group in the early Tertiary beds is of unusual interest.

Callocardia astartoides is the dominant species at the type locality and common at a number of other localities in the Cook Mountain formation.

Stations in Cook Mountain formation.

?8850 (c). 500 yards southwest of Espejo ranch, 8 miles south of Laredo, Webb County.

8833 (a). About 7 miles up the Rio Grande from Laredo, in Knob Bluffs, a quarter of a mile above pump of Santa Barbara farm, Webb County.

8768 (c). 1½ miles north of and a trifle east of the third gate, 7 miles southeast of Velenzuela ranch house, Webb County.

8770 (c). 39.9 miles north of Rio Grande City, Starr County, on river road to Zapata, just north of Lopeño post office, Zapata County.

Family TELLINIDAE.

Genus TELLINA (Linnaeus) Lamarck.

Tellina sp. A.

Plate XXXII, figures 8, 9.

Shell large, not very thin, much compressed, transversely ovate-trigonal in outline, nearly equilateral; umbones flat, inconspicuous except by reason of their position at the apex of an angle of not far from 120°; anterior and posterior dorsal margins nearly similar, the posterior declining, perhaps, a little more steeply; lateral extremities quite sharply rounded; base line symmetrically arcuate; an inconspicuous rostral fold developed near the posterior dorsal margin, defined rather by the abrupt change in the direction of the incrementals than by its elevation; surface sculpture incremental in character, least feeble posteriorly and toward the basal margin, becoming abruptly stronger behind the rostral fold and indicating by the undulation a second very obscure fold; characters of ligament and hinge not known; adductor scars commonly quite prominent; pallial sinus obscure but apparently very deep, produced almost to the anterior adductor, not confluent below.

The species is decidedly larger than any other found in the Eocene of Texas. A latitude of 40 millimeters is not uncommon and one cast, presumably identical, reaches an altitude of 40 with a probable latitude of 60 millimeters or more. Unfortunately, only casts, some of them with a few fragments of shell adhering, are preserved.

Stations in Cook Mountain formation.

8771 (p). 4 miles southeast of Laredo, Webb County.

6404 (p). 1 mile west of Canada Verde ranch, Webb County.

6436 (c). La Perla ranch below Laredo, Webb County.

?8837 (r). 3½ miles above San Ygnacio, Zapata County.

?8770 (p). Lopeño post office, Zapata County.

Family PHOLADIDAE.

Genus MARTESIA Leach.

Martesia? laredoënsis Gardner, n. sp.

Plate XXXII, figure 10.

Shell very thin, transversely elongated, tapering posteriorly, strongly inflated; anterior third of shell cut off by a deep but narrow groove, dropped from the umbones and extending obliquely backward; umbones low, conforming to the tubular outline of the shell, prosogyrate; anterior extremity rounding smoothly into the upcurved base; posterior dorsal and ventral margins slowly converging, the narrow lateral extremity vertically truncate; shell usually decorticated but so thin that the sculpture is reflected on the cast; a concentric sculpture, incremental in character and more or less irregular, developed over the entire shell but stronger upon the anterior third; radials approximately equal in strength to the concentric rugae and, like them, somewhat irregular, developed only in front of the groove; characters of the hinge and of the interior not known.

Dimensions: Altitude, 9.0 millimeters; latitude, 20.0 ± millimeters.

Type locality: Station 6434, a quarter of a mile south of Espejo ranch, south of Laredo, in Webb County, Tex.

Martesia texana Harris is similar to this species in outline and general dimensions, but the umbones of the Cherokee County species are not so near to the anterior extremity, the groove cuts off decidedly more than the anterior third, and there is an apparent absence of any radial sculpture. No trace of either *M. texana* or *M. laredoënsis* has been found except at the type localities.

Station in Cook Mountain formation.

6434. A quarter of a mile south of Espejo ranch, south of Laredo, Webb County.

Family TEREDINIDAE.

Genus TEREDO Linnaeus.

Teredo maverickensis Gardner, n. sp.

Tubes of moderate dimensions, somewhat irregular in growth habit though tending to follow the grain of the wood; closely and quite sharply rugose; characters of valves not known.

Dimensions: Diameter, 6.0 millimeters; thickness of shell, 0.6 millimeters.

Type locality: Station 1/277, Rio Grande, lower end of Maverick County, about 40 feet below Midway-Wilcox contact.

This teredo, which packs a large fragment of fossilized wood, is the first that has been reported from the Midway of the Gulf. It differs from the later Eocene teredos in the less regular growth habits and particularly in the very decided, close, sharp wrinkling of the surface. The value of these differences is increased by the difference in the habitat. It is interesting to find a record of the unfortunate appetite of this animal in the Midway of Texas.

Station in Midway formation.

1/277. Rio Grande, lower end of Maverick County, about 40 feet below Midway-Wilcox contact.

GASTROPODA.

Family CERITHIIDAE.

Genus CERITHIUM Bruguière.

Cerithium? sp. A.

Plate XXIX, figures 1, 2.

Internal casts of *Cerithium*-like forms occur in considerable numbers in southwestern Texas and serve as excellent horizon markers of the Midway. These casts indicate a rudely biconic shell with the maximum diameter in front of the median horizontal. The whorls of the conch were probably about 6 or 7 in number, rudely trapezoidal in outline and increasing quite rapidly in diameter. The body was smoothly rounded in the adults, though probably rather acutely angulated in the young. Some individuals show a suggestion of an irregular *Cerithium*-like ribbing. The aperture was apparently between one-third and one-half as long as the entire shell and was obliquely lenticular in outline. A specific name is reserved in the hope that the shell may come to light later. In the meantime these easily recognizable casts may be of service in indicating the Midway age of the formation in which they are carried.

Dimensions of imperfect figured specimen: Altitude, 42.0 millimeters; maximum diameter, 21.0 millimeters.

Stations in Midway formation.

3180 (p). Bluff on Frio River, half a mile below Myrick's (Evans's) apiary, Uvalde County.

6576 (c). Land of Indio Cattle Co., 1¼ miles below White Bluff, about 4½ miles southwest of Jacal ranch house, Maverick County.

8799 (p). Texas side of the Rio Grande 1 mile below the Blessé ranch house, Maverick County.

CEPHALOPODA.

Family CLYDONAUTILIDAE Hyatt.

Genus ENCLIMATOCERAS Hyatt.

Enclimatoceras vaughani Gardner, n. sp.

Plate XXXIII.

Shell large, rather compressed toward the apex, more broadly rounded ventrally toward the aperture, obliquely flattened laterally; whorls numerous, increasing but slowly in latitude; the altitude of the earlier whorls a little more than three times their average width from suture to suture, of the later whorls a little less; final whorl of a half grown specimen rudely reniform in outline, somewhat auriculate laterally, concave, the diameter of the whorl approximately double the altitude; umbilici quite strongly depressed, their peripheries obscurely carinate; ventral saddle very broad and nearly horizontal; lateral lobes broad and very shallow; lateral saddles relatively narrow and moderately deep; siphuncle dorsad, migrating slowly toward the center with increasing age; surface not known.

Dimensions: Maximum diameter of shell, 168.0 ± millimeters; diameter of shell at right angles to maximum diameter, 140.0 ± millimeters; thickness 100.0 millimeters. Adolescent individual: Maximum diameter of shell, 93.0 ± millimeters; diameter of shell at right angles to maximum diameter, 64.0 ± millimeters; maximum thickness, 73.0 ± millimeters. A larger but imperfect individual attains a maximum diameter of 220.0 millimeters.

Type locality: Station 3178, three-fourths mile northwest of Myrick's (Evans's) apiary, Frio River, Uvalde County.

Enclimatoceras vaughani is the Texas analogue of *Enclimatoceras ulrichi* (White), of the Midway of Alabama, a form very similar in general dimensions and outline. The adult *E. vaughani* are, as a rule, more compressed than the adult *E. ulrichi*, but the young of the two species show similar ranges of variation.

The umbilici also seem to be a little more depressed in the Texas species. The most obvious and constant difference, however, is in the outline of the lobes and saddles. The sutures in *E. ulrichi* are much more flexuous than those of *E. vaughani*. In *E. vaughani* the ventral saddle is nearly horizontal and the lateral lobes exceedingly shallow. In *E. ulrichi* the ventral saddle is perceptibly arcuate and the lateral lobes are strongly incurved. The lateral saddles are well developed in both species, though they are deeper in the Texas form.

I have the honor of dedicating this species to Dr. T. Wayland Vaughan.

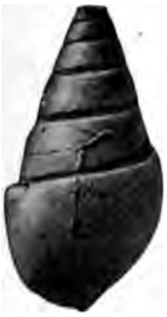
Stations in Midway formation.

3178 (p). Three-fourths mile northwest of Myrick's (Evans's) apiary, north of Frio River, Uvalde County.

3179 (p). Half a mile northwest of Myrick's (Evans's) lower apiary, south side of Frio River, Uvalde County.

Frio River half a mile above Bob Evans's (formerly Myrick's) apiary, Uvalde County.

PLATES XXIX-XXXIII.



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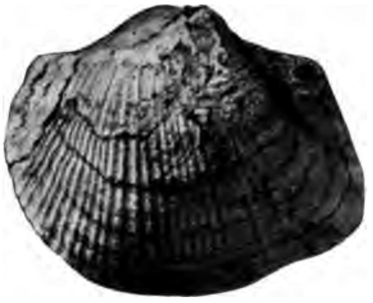

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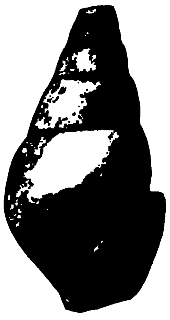

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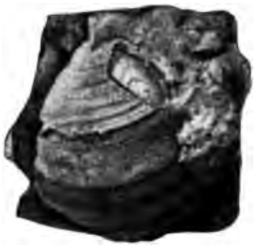

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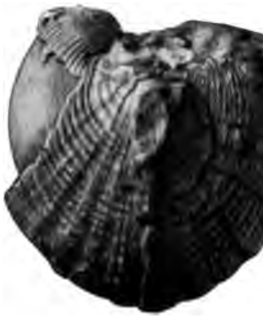

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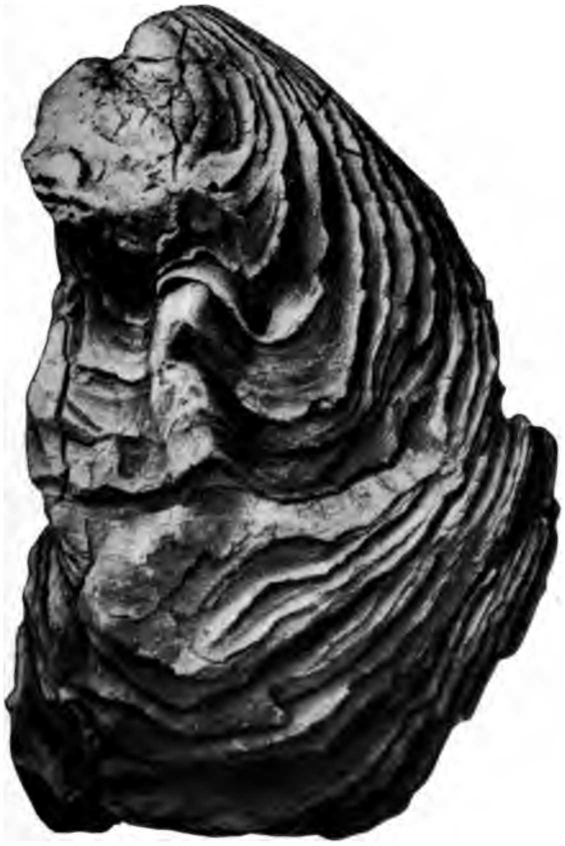

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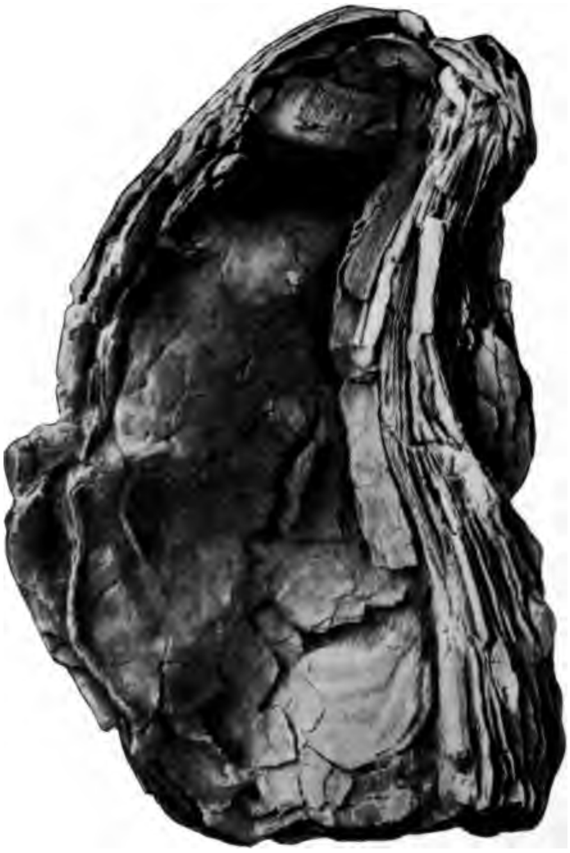

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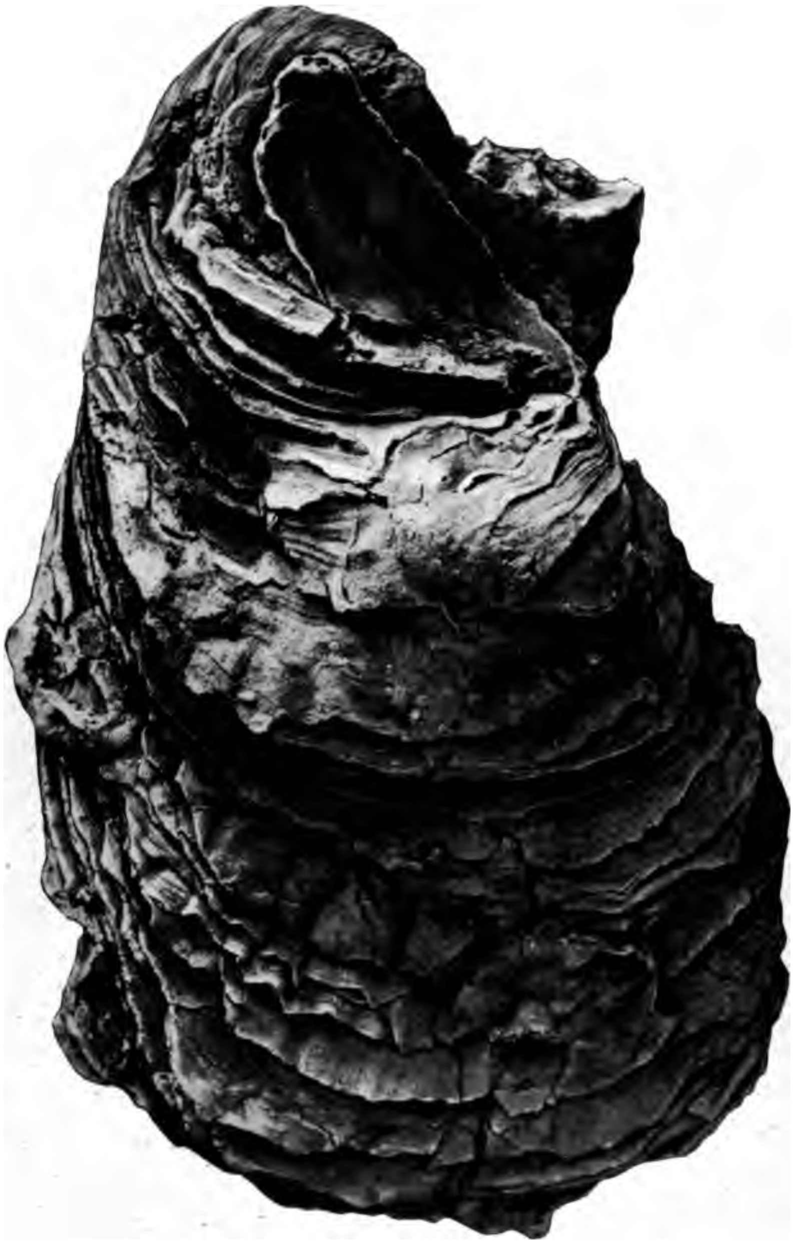
EOCENE MOLLUSCA FROM SOUTHWESTERN TEXAS.

1, 2. *Cerithium?* sp. A. **1,** Dorsal view, × 1; **2,** apertural view, × 1.

3. *Nucula* sp. Exterior of right valve, × 1.

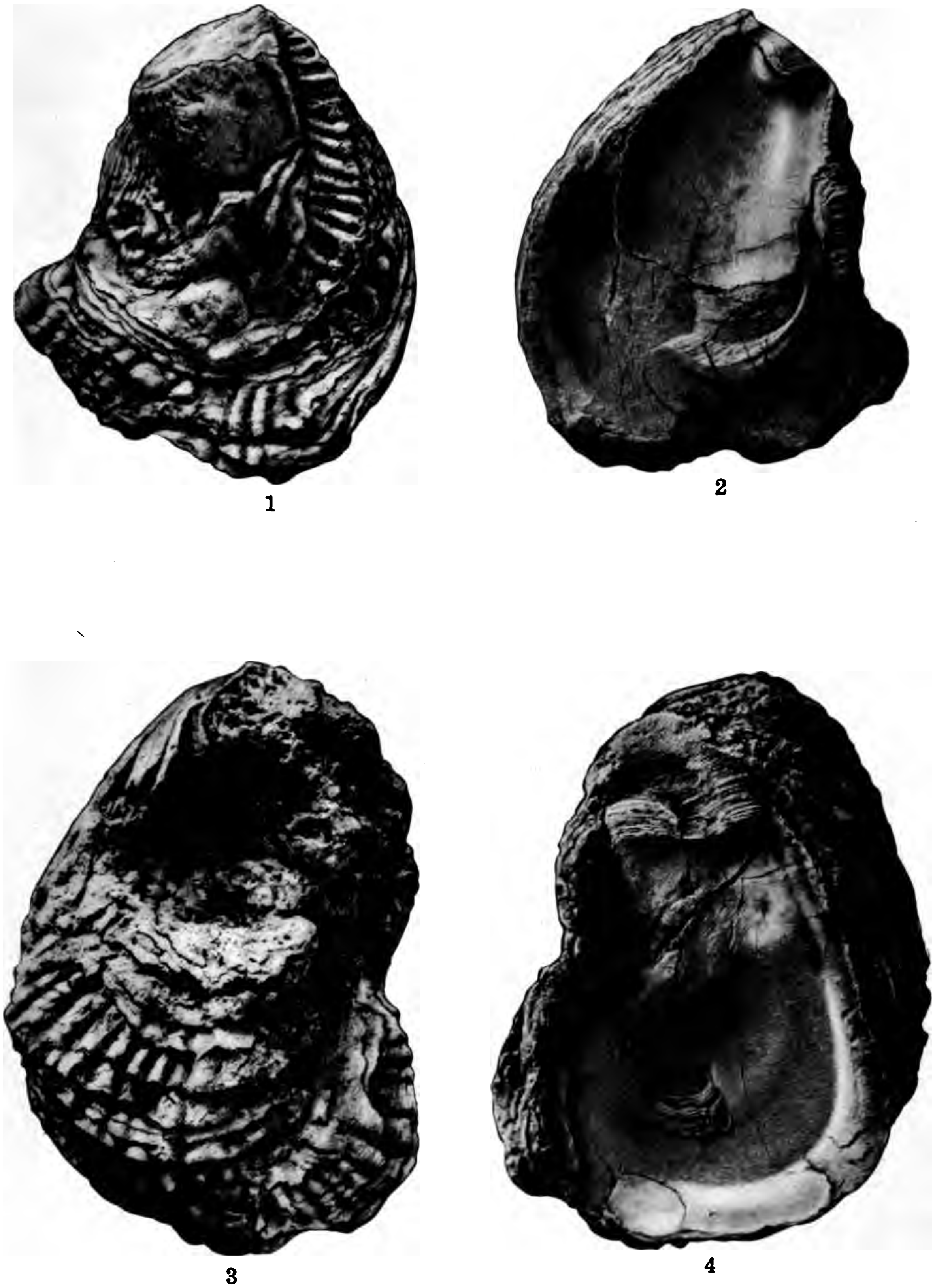
4, 5. *Cucullaea* (*Macrodonta* subsp. ?) *texana* Gardner, n. subsp. **4,** Front view, × 1; **5,** exterior of left valve, × 1.

6, 7. *Ostrea alabamiensis* subsp. *georgiana* Conrad. **6,** Exterior of left valve, × 1; **7,** interior of left valve, × 1.



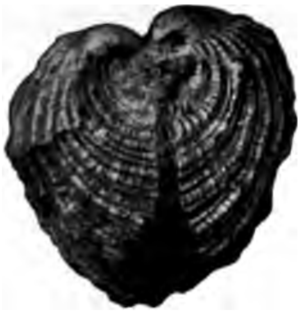
EOCENE MOLLUSCA FROM SOUTHWESTERN TEXAS.

Ostrea alabamiensis subsp. *georgiana* Conrad. Exterior of right valve, × 1.



EOCENE MOLLUSCA FROM SOUTHWESTERN TEXAS.

1–4. *Ostrea tasex* Gardner, n. sp. **1,** Exterior of left valve, × 1; **2,** interior of left valve, × 1; **3,** exterior of right valve, × 1; **4,** interior of right valve, × 1.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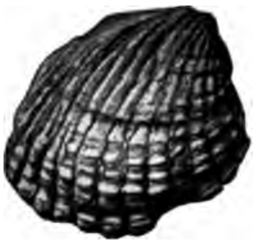
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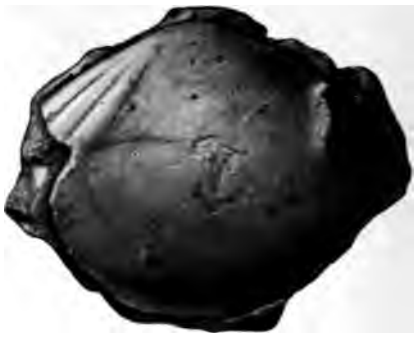
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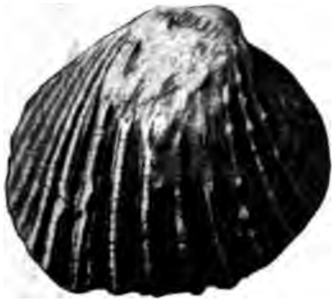
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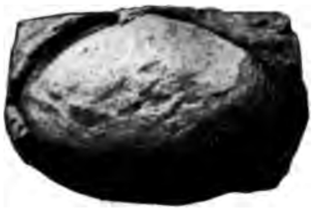
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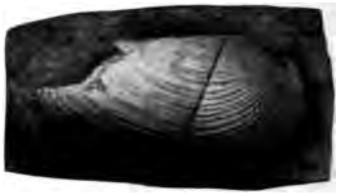
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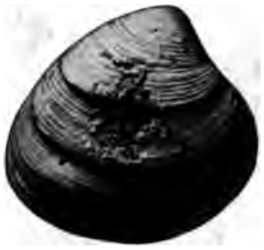
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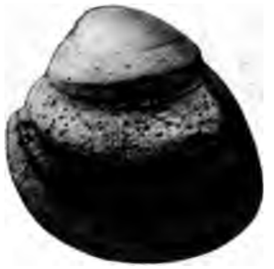
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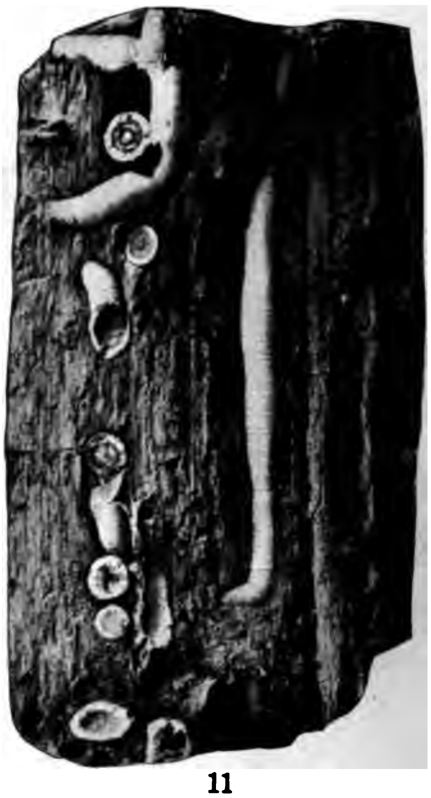
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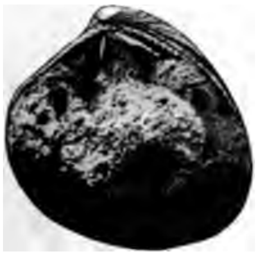
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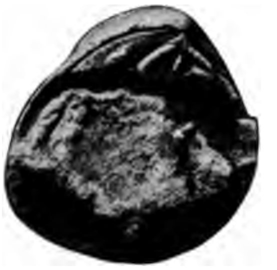
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EOCENE MOLLUSCA FROM SOUTHWESTERN TEXAS.

1, 2. *Venericardia* ~~*alticostata*~~ subsp. *hesperia* Gardner, n. subsp. **1,** Front view, × 1; **2,** exterior of right valve, × 1.

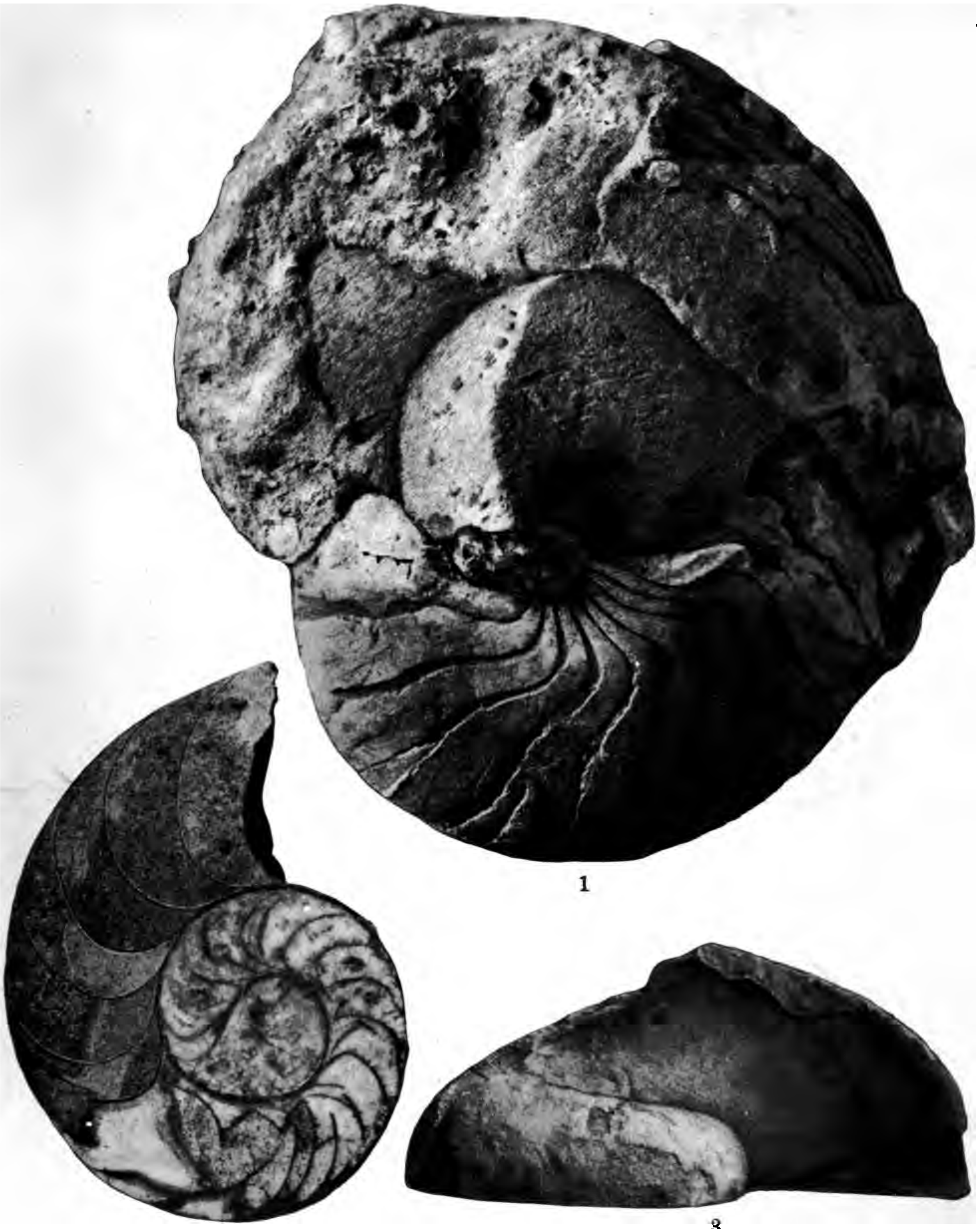
3. *Venericardia alticostata* subsp. *whitei* Gardner, n. subsp. Exterior of right valve, × 1.

4-7. *Callocardia astartoides* Gardner, n. sp. **4,** Exterior of right valve, × 2; **5,** interior of right valve, × 2; **6,** exteriorof left valve, × 2; **7,** interior of left valve, × 2.

8, 9. *Tellina* sp. A. **8,** Internal cast of left valve, × 1; **9,** internal cast of left valve, × 1.

10. *Martesia laredoënsis* Gardner, n. sp. External cast of right valve, × 2.

11. *Teredo maverickensis* Gardner, n. sp. Longitudinal views and natural cross sections of tubes in fossil wood, × 1.



EOCENE MOLLUSCA FROM SOUTHWESTERN TEXAS.

1-3. *Enclimatoceras vaughani* Gardner, n. sp. **1,** Lateral view × 1; **2,** cross section of adolescent individual, × 1; **3,** apertural view of adolescent individual, × 1.

PRELIMINARY REPORT ON FOSSIL VERTEBRATES OF THE SAN PEDRO VALLEY, ARIZONA, WITH DESCRIPTIONS OF NEW SPECIES OF RODENTIA AND LAGOMORPHA.

By James W. Gidley.

INTRODUCTION.

On the initiative of the United States Geological Survey and with the cooperation of the United States National Museum, I was privileged during February, March, and part of April, 1921, to collect fossil vertebrates in the San Pedro Valley, Ariz., where remains had previously been located by Kirk Bryan, of the Geological Survey. The results of this expedition are here published in part.

The special problem involved was the determination of the age of the sedimentary deposits, which up to that time had been termed Pleistocene. Two localities, apparently at slightly different horizons, yielded material representing a fauna sufficiently varied and distinctive to establish their age as Pliocene.

The locality first visited is a small area of badlands about 3 miles east of the Curtis ranch, which is on the State road about 14 miles northwest of Tombstone and an equal distance southeast of Benson by road. The second locality is west of the State road about 2 miles south of Benson. These two localities are about 12 miles apart and on opposite sides of the San Pedro Valley. The first locality yielded by far the greater bulk of material, but the species represented in the collection from the second are more numerous. Stratigraphically there seems to be no difference in the level of the beds of the two localities, and structurally they are very similar, yet, so far as I am able to determine, they contain no species in common. Because of this fact, as well as the general character and assemblage of the forms represented, I am led to consider them as of slightly different age, the beds at the Benson locality being apparently the older.

Most of the mammal material is fragmentary, but several good specimens were procured, including enough material for the restoration of the dermal armor and skeleton of a *Glyptotherium* and a possible skeletal restoration of a mastodon, both from the Curtis locality. The material from the Benson locality here described was all collected at one spot, a fossil bone quarry opened up and worked by Kirk Bryan and me. Immediately associated material from this quarry includes fragmentary specimens of *Hipparion*, *Pliauchena?*, *Platygonus*, and *Pliohippus* or *Hippidium?*, together with a new species of box turtle and eight new species of birds, not all of which are satisfactorily definable from the scanty material obtained.

The greater part of the specimens included in these collections have not yet been prepared, but those belonging to the orders Rodentia and Lagomorpha have been cleaned and studied, and the new species are here described. Those from the Curtis locality were all found during the excavation of one of the mastodon skeletons. Immediately associated with them were remains of a llama, a canid, a mustilid, a small land turtle, an edentate, and two species of small birds.

A tentative list of the orders, families, genera, and species, so far as they have been determined, represented in each locality is given on page 120.

Preliminary list of fossil vertebrates from the San Pedro Valley, Ariz.

	Number of species.	
	Benson.	Curtis.
MAMMALIA.		
Proboscidia:		
Elephantidae:		
Cf. *Dibelodon*, probably n. sp	......	2
Cf. *Gompotherium*, probably n. sp.	1	......
Perissodactyla:		
Equiidae:		
Equus, undet	......	2
Pliohippus, undet	1	......
Hipparion, undet	1	......
Artiodactyla:		
Camelidae:		
Lama, n. sp	......	1
Cf. *Procamelus*, undet	1	1
Cf. *Pliauchenia*, undet	1	1
Tayassuidae:		
Platygonus cf. *P. vetus*, or n. sp	1	......
Cervidae:		
Odocoileus, n. sp	......	1
Merycodus near *M. necatus*	1	1
Cf. *Merycodus*, n. sp	......	1
Carnivora:		
Canids, 3 n. sp	1	2
Felid?, n. sp	......	1
Mustilid, sp	1	1
Rodentia:		
Sciuridae:		
Citellus cochisei, n. sp	......	1
Citellus bensoni, n. sp	1	......
Geomyidae:		
Geomys parvidens, n. sp	......	1
Geomys minor, n. sp	1	......
Cratogeomys bensoni, n. sp	1	......
Heteromyidae:		
Dipodomys minor, n. sp	1	......
Muridae:		
Subfamily Cricetinae:		
Peromyscus brachygnathus, n. sp	1	......
Peromyscus minimus, n. sp	1	......
Peromyscus sp	1	......
Eligmodontia arizonae, n. sp.	1	......
Onychomys pedroensis, n. sp.	......	1
Onychomys bensoni, n. sp	1	......
Sigmodon curtisi, n. sp	......	1
Sigmodon minor, n. sp	......	1
Sigmodon medius, n. sp	1	......
Subfamily Neotomeniae:		
Neotoma fossilis, n. sp	1	......
Subfamily Microteinae:		
Neofiber sp	......	1
MAMMALIA—continued.		
Lagomorpha:		
Leporidae:		
Lepus, 3 sp., possibly new	2	1
Sylvilagus or *Brachylagus* sp	1	......
Edentata:		
Glyptodontidae:		
Glyptotherium, n. sp	......	1
Total Mammalia	23	22
REPTILIA.		
Testudines:		
Testudinidae:		
Testudo, 2 sp. undet	1	1
Kinosternodae:		
Kinosternon, new sp	1	1
Batrachia:		
Salientia:		
Ranidae:		
Rana or *Bufo*, not yet determined	1	......
Total Reptilia	3	2
AVES.		
Galliformes:		
Odontophoridae:		
Undetermined	......	1
Colinus sp. undet	1	......
Family undet	1	......
Anseriformes:		
Anatidae:		
Dendrocygna, n. sp	1	......
Branta, n. sp	1	......
Charadriiformes:		
Scolopacidae:		
Micropalama, n. sp	1	......
Family undet., medium-sized form	1	......
Columbiformes:		
Family undet. A pigeon somewhat smaller than the domestic dove	......	1
Passeriformes:		
Fringillidae:		
Small sp., undet	1	......
Other passerines represented by scanty material	1	1
Total Aves	8	3

The reptilian remains, including at least two species of turtles, probably new, are being described by C. W. Gilmore, and the bird bones are being studied and will be described by Alexander Wetmore, of the Biological Survey, Department of Agriculture. The tentative lists of Reptilia and Aves given above are furnished by these gentlemen.

GEOLOGIC HORIZON AND CLIMATIC CONDITIONS INDICATED.

This preliminary study reveals little positive evidence regarding the exact geologic horizon of the beds in San Pedro Valley, beyond what is stated above. They seem to be clearly Pliocene, and the peculiar mingling of modern and more ancient forms seems to point rather definitely to a late stage of Pliocene time. Unfortunately, the material of these collections represents for the most part new species that can not be correlated with known faunas of other localities where the age of the beds has been established. However, the species are sufficiently numerous and varied to constitute a standard for comparison, and future field work in this region will almost certainly bring to light material that will definitely and correctly determine the proper sequence of these deposits.

The facts that there are here two or three species of true horse (*Equus*) and that the rodents are all referable to modern genera, some of which are found living in this general region, may suggest Pleistocene age. But to offset this evidence of a seemingly more modern fauna, the mastodons and glyptodonts are of distinctly Pliocene types, and one of the canids, though modern in skull and dental modifications, has the type of humerus belonging to the Miocene and Pliocene canids, in that the entepicondylar foramen is prominently present. This feature and the presence of *Hipparion*, *Pliohippus*, and *Merycodus*, together with the fact that the 15 or more species of rodents include no living species, constitute rather conclusive evidence of a faunal assemblage that is older than Pleistocene.

This general assemblage of species, including proboscidians, camels, horses, glyptodonts, and an extinct species of the ocellated turkey related to a group now living only in Central America and southern Mexico, suggests that the climate at the time the beds were laid down was rather warm and moist, probably subtropical or even tropical.

The presence of a true llama, the glyptodont, and a rodent belonging to a genus now living only in South America seems to indicate an intermingling of forms of South American origin, and the presence in these Pliocene deposits of a rodent and camel of definite South American living types suggests the derivation of their South American relatives from North America and favors the suggestion of an exchange of faunas between the two continents which took place somewhere near this epoch of geologic time.

DESCRIPTIONS OF SPECIES.

Order RODENTIA.

The order Rodentia is represented in the San Pedro Valley by 17 species, 11 of which occur at the Benson locality and 6 at the Curtis locality. Of these species, 15 are here described as new, and 2 are not certainly determined on the scanty material in hand. However, though all the species represented seem to be new, each is readily referable to one of ten living genera, distributed among four families—the Sciuridae, Geomyidae, Heteromyidae, and Muridae. The species belonging to the Muridae represent three subfamilies—the Cricetinae, Neotomeniae, and Microteinae.

Family SCIURIDAE.

The family Sciuridae is represented by two new species, both belonging to the genus *Citellus*.

Citellus cochisei Gidley, n. sp.

Plate XXXIV, figures 1, 2.

Type.—Portion of a right maxillary containing all the cheek teeth (catalog No. 10490, U. S. Nat. Mus.).

Paratype.—Portion of a left lower jaw (catalog No. 10491).

Locality.—Both are from the Curtis locality, in sec. 25, T. 18 S., R. 21 E., and were found in exhuming a mastodon skeleton.

Description.—Length of upper cheek-tooth series 10.5 millimeters. Molars relatively wide, m^1 and m^2 one-third wider than long; lophs and valleys simple and narrow; both posterior transverse lophs of the molars completely united with protocone, forming a short, narrow valley opening outward and extending inward not more than one-half the width of the tooth crown, as in *Cynomys*. The anterior transverse lophs are more depressed and except in m^3 are much longer than the other lophs, extending inward and upward to disppear in the anterior wall of the protocone. P^4 differs from the anterior two molars only in being less wide and in having the anterior loph relatively and actually more extended anteriorly.

In the greater width of tooth crowns, the less extent of their median external reentrant valleys, and the relative shortness of the heel of the last molar, this species suggests *Cynomys*, but it differs from species of that genus in the much more brachyodont tooth crowns, the greater relative depth of the median external reentrant valleys, and the incipiency, amounting to almost total absence, of the posterior reentrant valleys so prominent in species of *Cynomys*. The first of these features might be considered as a character of degree only, indicating less advanced specialization, but the other two I consider characters that denote relationship with the living species of *Citellus* rather than with those of the genus *Cynomys*.

The lower jaw, as indicated by specimen No. 10491, which carries the incisor and the anterior two cheek teeth, is relatively short and deep, the incisor narrow and pointed, and the cheek teeth relatively wide to a degree corresponding with those of the upper series. This species compares in size with *C. evermani*, but it differs from all the living forms in one or more of the characters enumerated above.

Citellus bensoni Gidley, n. sp.

Plate XXXIV, figures 3, 4.

Type.—A first or second upper molar of the right side and a last upper molar of the left side (catalog No. 10531, U. S. Nat. Mus.).

Paratype.—The cheek-tooth series of a left lower jaw (catalog No. 10532, U. S. Nat. Mus.).

Locality.—Both from the Benson locality.

Description.—Length of cheek-tooth series (estimated from measurements of the paratype), 10.3 millimeters; upper molar of about the same proportion as the corresponding one of *C. cochisei* at the base but much narrower at the summit, owing to the greater slope of the inner wall of the protocone; the three transverse lophs about equal in length, the posterior one being broken up into two distinct but slightly joined cuspules, the inner one of which is a rounded cone entirely disconnected from the protocone.

An upper m^3 which I associate with the type specimen, like that of *C. cochisei*, has a relatively small heel portion as compared with living species, and in addition there is a well-defined isolated cone-shaped cuspule near the center of the posterior basin.

This species seems to approach *C. beecheyi* much more closely than any other living species but differs from it in a few apparently important particulars. In *C. beecheyi* the crowns of the upper molars are relatively narrower than in the fossil species, being nearly as long as wide; the lingual wall of the protocone is less sloping, and the exterior or buccal face of this cusp is much more sloping. Other differences noted in the living species are the generally less broken up condition of the posterior transverse lophs; the somewhat shallower transverse valleys, the posterior one of which usually has a small cuspule at its external entrance; and the relatively broader and less completely inclosed posterior valley of the last upper molar.

Beyond the fact that the last lower molar, like the upper, is relatively smaller, and the valleys and cusps are somewhat more sharply defined than in *C. beecheyi*, there is little to distinguish between the lower cheek teeth of that species and *C. bensoni*.

Family GEOMYIDAE.

Three new species referable to two living genera of geomids are represented in the collection.

Geomys parvidens Gidley, n. sp.

Plate XXXIV, figures 5, 6.

Type.—The anterior portion of a skull carrying the incisors and all the cheek teeth except the first and last of the right side (catalog No. 10492, U. S. Nat. Mus.).

Paratype.—Portion of the right lower jaw carrying all the teeth except m^3 (catalog No. 10493, U. S. Nat. Mus.).

Locality.—Both from the Curtis locality.

Description.—Length of upper cheek-tooth series 5.5 millimeters; width across first upper molars (measured to outer borders) 6.7 millimeters; size small, about the same as that of *Geomys texensis;* rostrum relatively short and heavy; incisors with two very unequal grooves, the smaller one close to the inner border of the crown, the larger one almost exactly bisecting its anterior face, making the outer of the three ridges thus formed slightly but definitely largest; the cheek teeth are relatively small and not greatly expanded laterally, m^1 and m^2 being almost evenly elliptical in outline but with the outer edges slightly compressed; p^4 with anterior lobe decidedly smaller and less laterally expanded than the posterior one; m^3 as wide as long, subtriangular, relatively small.

Besides being about equal in size to *G. texensis*, *G. parvidens* is almost identical with that species in the character of the incisors, but it differs from *G. texensis* and the other living species of the genus in general in the less lateral expansion of the cheek teeth, the shorter and deeper rostrum, and the less progressive character of p^4.

The lower jaw referred to this species is relatively short, with prominent masseteric ridge and the submental foramina lying almost directly under the anterior end of the masseteric ridge. The anterior lobe of p_4 is relatively small and subcircular, with the walls very little flattened.

Geomys minor Gidley, n. sp.

Plate XXXIV, figures 7, 8.

Type.—Portion of a right lower jaw lacking the last molar (catalog No. 10494, U. S. Nat. Mus.).

Paratype.—A right upper incisor (catalog No. 10534, U. S. Nat. Mus.).

Locality.—Both from the Benson locality.

Description.—Length of cheek-tooth series (estimated) 5.4 millimeters; the jaw is slightly smaller than that of *G. parvidens* and differs from it otherwise in having the anterior masseteric area more depressed, the submental foramen slightly farther back in position, the cheek teeth relatively larger, and the anterior lobe of p_4 more nearly circular in outline; no anterior fossa between cheek teeth and coronoid process.

An associated upper incisor tooth is of appropriate size for the species It shows the characteristic grooving of a true *Geomys*, and it is this fact which has determined the generic reference of *G. minor*.

Cratogeomys bensoni Gidley, n. sp.

Plate XXXIV, figures 9–11.

Type.—A portion of a left lower jaw carrying all teeth (incisors broken) (catalog No. 10495, U. S. Nat. Mus.).

Paratype.—An upper incisor (catalog No. 10496, U. S. Nat. Mus.).

Locality.—Benson locality. The species is represented by four other pieces of the lower jaws from the same locality.

Description.—Length of cheek-tooth series 8 millimeters (measured at summits of teeth). About the size of the living species *Geomys breviceps;* cheek teeth not greatly compressed; p^4 with outer reentrant angle rather widely V-shaped, the inner one forming a distinct U; posterior wall of last molar in the type specimen with two distinct and two faint parallel longitudinal grooves forming three low but distinct closely grouped median longitudinal enamel ridges.

This species differs from all living species of geomids examined in having the area of the anterior portion of the masseteric ridge more depressed and in the position of the anterior submental foramen, which is nearly as in the two above-described species of *Geomys*. In living species this foramen is anterior to the masseteric ridge and nearly level with it. In the fossil species it is lower and more posterior in position, lying almost directly under the anterior extremity of the masseteric ridge. There is also between the cheek teeth and the anterior border of the coronoid process in *C. bensoni* a narrow but distinctly marked longitudinal fossa.

This species is referred to *Cratogeomys* on the evidence of an associated upper incisor of appropriate size which has the single groove characteristic of this genus.

Dipodomys minor Gidley, n. sp.

Plate XXXIV, figure 16

Type.—A nearly complete right lower jaw containing the incisor and the first cheek tooth (catalog No. 10499, U. S. Nat. Mus.).

Locality.—Benson locality.

Description.—Length of cheek-tooth row, measured from extreme borders of the alveoli, 4.7 millimeters; size and general jaw characters about as in the living species *Perodipus chapmani*, differing only in its more slender proportions and in the somewhat more reduced condition of the coronoid process. The fourth lower premolar, the only one of the cheek-teeth series present, is a long crowned and anteriorly curved tooth which is double-lobed, the anterior lobe having an anterior reentrant angle as in *P. chapmani*, but this tooth differs from the tooth of that species in having the posterior lobe relatively wider. Also the alveolus of the last molar is only about one-half the width of that of the other molars, indicating that this tooth is relatively more reduced than in the living species.

Family MURIDAE.

The family Muridae is rather abundantly represented at both localities. The 12 determinable species are distributed among three subfamilies, 10 belonging to the Cricetinae, 1 to the Microtinae, and 1 to the Neotomeniae.

Genus PEROMYSCUS.

Specimens found at the Benson locality are referable to three species of *Peromyscus*. Two of these are new, although one is apparently closely related to the *P. taylori* group. The other new species is more distinctive. The third, represented by a single lower jaw lacking the cheek teeth, has not been determined.

Peromyscus brachygnathus Gidley, n. sp.

Plate XXXIV, figure 12.

Type.—The greater portion of a right lower jaw carrying all the teeth (catalog No. 10501, U. S. Nat. Mus.).

Locality.—Curtis locality.

Description.—Length of cheek-tooth series, 2.8 millimeters; about the size of *P. taylori;* jaw relatively short anterior to cheek teeth; last molar very much reduced, as much as in any living species of *Onychomys*. The teeth are too much worn to determine accurately their normal height in unworn condition, but they appear to be of the depressed type of *P. taylori*.

The form and position of the anterior extension of the masseteric ridge, the general character of the coronoid region, and the relatively broadly expanded anterior lobe of the anterior cheek tooth seem to determine the generic reference of this species, but it differs from all living species of the genus in the relatively short jaw and the greater reduction of the last lower cheek tooth, which seems to have nearly or quite lost its hinder lobe.

Peromyscus minimus Gidley, n. sp.

Plate XXXIV, figure 13.

Type.—Portion of a left lower jaw carrying all the teeth (catalog No. 10500, U. S. Nat. Mus.).

Locality.—Benson locality.

Description.—Size very small, length of cheek-tooth series 2.6 millimeters; cheek-tooth cusps depressed, with well-marked cingula at the entrance of the external valley, and with tendency to inclose the internal ones by an uprising of the inner enamel wall between the cusps; anterior lobe of the first cheek tooth, p_4, relatively narrow but two-cusped at the summit; posterior lobe of last cheek tooth small, almost as much reduced as in *Onychomys*.

This species seems more nearly related to *P. taylori* than to any other living species but differs from it in having a narrow divided anterior lobe of the first cheek tooth and a more reduced hinder molar. It further differs from that species and more nearly agrees with others of the genus in the wider angle at which the coronoid portion of the ascending ramus diverges from the alveolar portion of the jaw.

P. minimus is distinguished from *P. brachygnathus* in that the jaw is somewhat more slender in proportions; the masseteric ridge is less advanced forward; the cheek teeth are slightly narrower; the anterior lobe of the first cheek tooth is narrow and double cusped, while that of *P. brachygnathus* is wider and undivided, and the last cheek tooth is somewhat less reduced.

Peromyscus sp.

Plate XXXIV, figure 14.

A second and larger species, about equaling *Peromyscus m. gambeli* in size, is represented by a lower jaw (catalog No. 10502, U. S. Nat. Mus.) lacking all the cheek teeth. Length of cheek-tooth series as estimated by measurement of the alveoli, 3.8 millimeters. This jaw, in its general form and in the position of the anterior extremity of the masseteric ridge, is sufficiently characterized to make certain its generic reference, but its specific features can not be determined until the cheek teeth are known.

Genus ELIGMODONTIA.

The genus *Eligmodontia*, the living species of which are confined to the South America continent, is represented by a single species in the fossil collection from Arizona.

Eligmodontia arizonae Gidley, n. sp.

Plate XXXIV, figure 15.

Type.—Greater portion of a left lower jaw containing the complete dentition (catalog No. 10503, U. S. Nat. Mus.).

Paratype.—Single lower jaws of two other individuals (catalog Nos. 10504, 10505).

Locality.—All from Benson locality.

Description.—Length of cheek-tooth series 3.6 millimeters; about the size of the living species *E. morgani*, but may be distinguished from it by its relatively greater depth of jaws, its decidedly shorter symphysis, and the less reduced condition of the last molar.

The anterior lobe of the first cheek tooth is distinctly notched by an anterior median reentrant angle, as is usual in *Peromyscus*, whereas in the living species of *Eligmodontia* this lobe is usually evenly convex in front. The fossil species from Arizona, however, is readily distinguished from *Peromyscus* by the characters which ally it to *Eligmodontia*, namely, by the form and position of the masseteric ridge, which extends forward to the extreme anterior border of the cheek-tooth series; by the form and situation of the capsular process for the reception of the base of the incisor, which is placed high upon the ascending ramus and is marked by a decided sulcus between it and the coronoid; and by the form of the last cheek tooth, which in species of *Eligmodontia* is more reduced than in *Peromyscus*.

Onychomys pedroensis Gidley, n. sp.

Plate XXXV, figure 1.

Type.—Portion of a left lower jaw carrying the first and last cheek teeth (catalog No. 10506, U. S. Nat. Mus.).

Paratypes.—Other lower jaw portions (catalog Nos. 10507, 10508, U. S. Nat. Mus.).

Locality.—All from Curtis locality.

Description.—Length of the cheek teeth 4.5 millimeters; size somewhat larger than *O. leu. ruidosae*, which it somewhat more nearly resembles than any other living species. It further differs from that species in its relatively greater depth of jaw, the greater degree to which the masseteric ridge is carried forward, and the somewhat less reduced condition of the last cheek tooth.

Onychomys bensoni Gidley, n. sp.

Plate XXXV, figure 3.

Type.—Portion of a right lower jaw containing complete dentition (catalog No. 10509, U. S. Nat. Mus.).

Locality.—Benson locality.

Description.—Length of cheek-tooth series 3.9 millimeters; about the size of *O. torridus* but with less reduced last molar, as in the larger species *O. leu. ruidosae*. The hinder lobe of the last molar is less reduced even than in the last-mentioned species. *O. bensoni* differs from all the living species of the genus in having more widely open valleys and less conspicuous lophs in the molar teeth; a more depressed heel on the last lower molar, which is distinctly lower than the anterior or triconid portion; and apparently a relatively larger and higher coronoid process.

Sigmodon curtisi Gidley, n. sp.

Plate XXXV, figure 2.

Type.—The greater parts of both lower jaws carrying complete dentition (catalog No. 10510, U. S. Nat. Mus.).

Paratype.—Portion of a right lower jaw with cheek teeth (catalog No. 10511, U. S. Nat. Mus.).

Locality.—Both from Curtis locality.

Description.—Length of cheek-tooth series 7 millimeters; about the size of *S. hispidus arizonae*, which it seems to resemble more nearly, but it differs from that as well as the other living species in the more open valleys of the reentrant angles, the more compressed lophs, the less hypsodont condition of the cheek teeth, the relatively deeper posterior inner reentrant valley of p_4 and m_1, and especially the form and proportions of the cusps of the last lower molar, which is relatively larger, with the hinder cusp relatively broader and fuller than in the living species. A feature that is characteristic of this and the species described below and is not observed in any of the living species is noted in the last molar, in which the great extension and flattening of the inner or lingual wall of the posterior lobe forms a sharp right angle with the posterior wall of the reentrant angle on that side.

I take pleasure in naming this species for Mr. Milton Curtis, in recognition of his efficient assistance in the field.

Sigmodon minor Gidley, n. sp.

Plate XXXV, figures 4, 5.

Type.—Portion of a left lower jaw carrying the complete dentition (catalog No. 10512, U. S. Nat. Mus.).

Paratype.—Portion of a left maxillary carrying the anterior two cheek teeth (catalog No. 10513, U. S. Nat. Mus.).

Locality.—Curtis locality. Five other lower-jaw portions, most of them with complete

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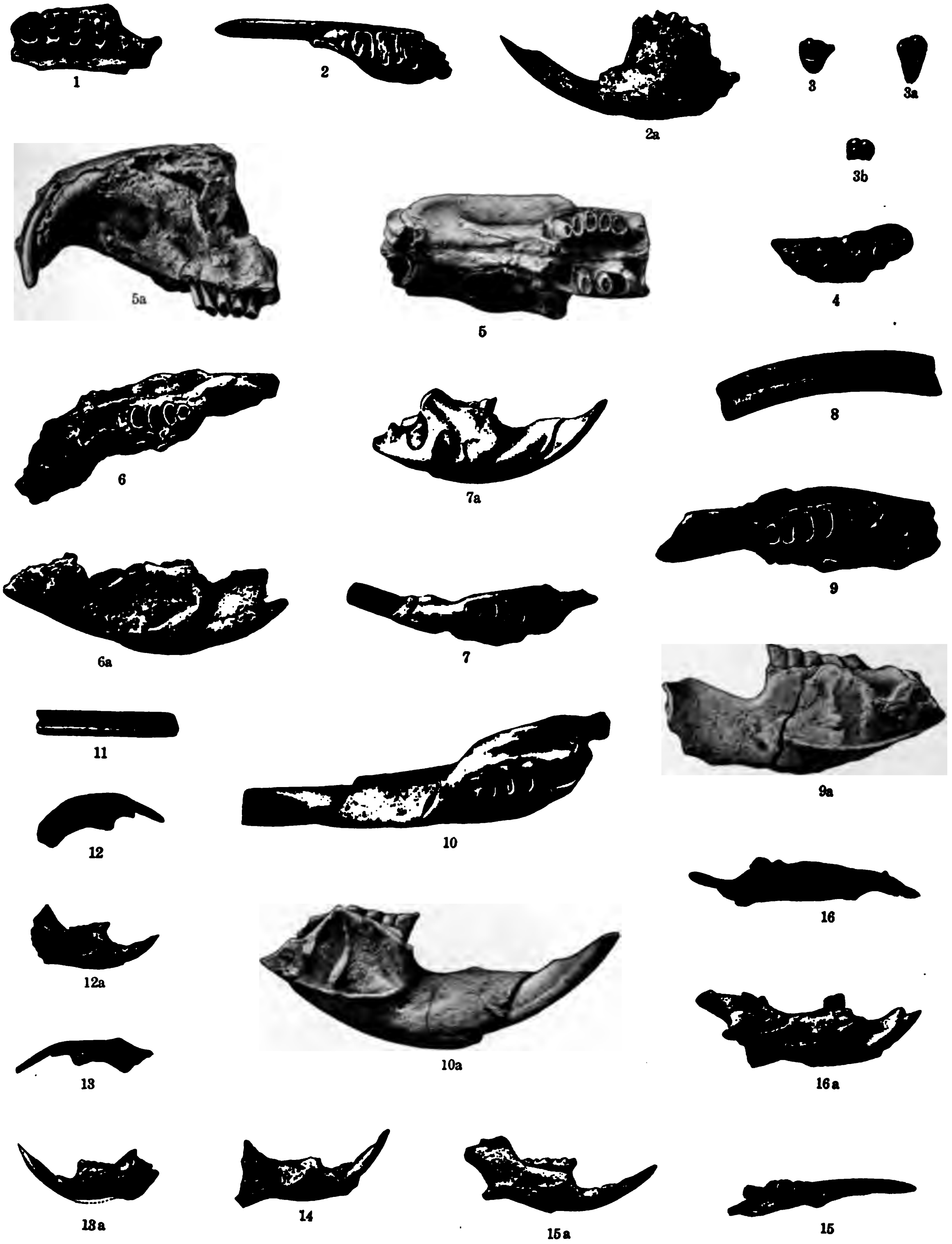
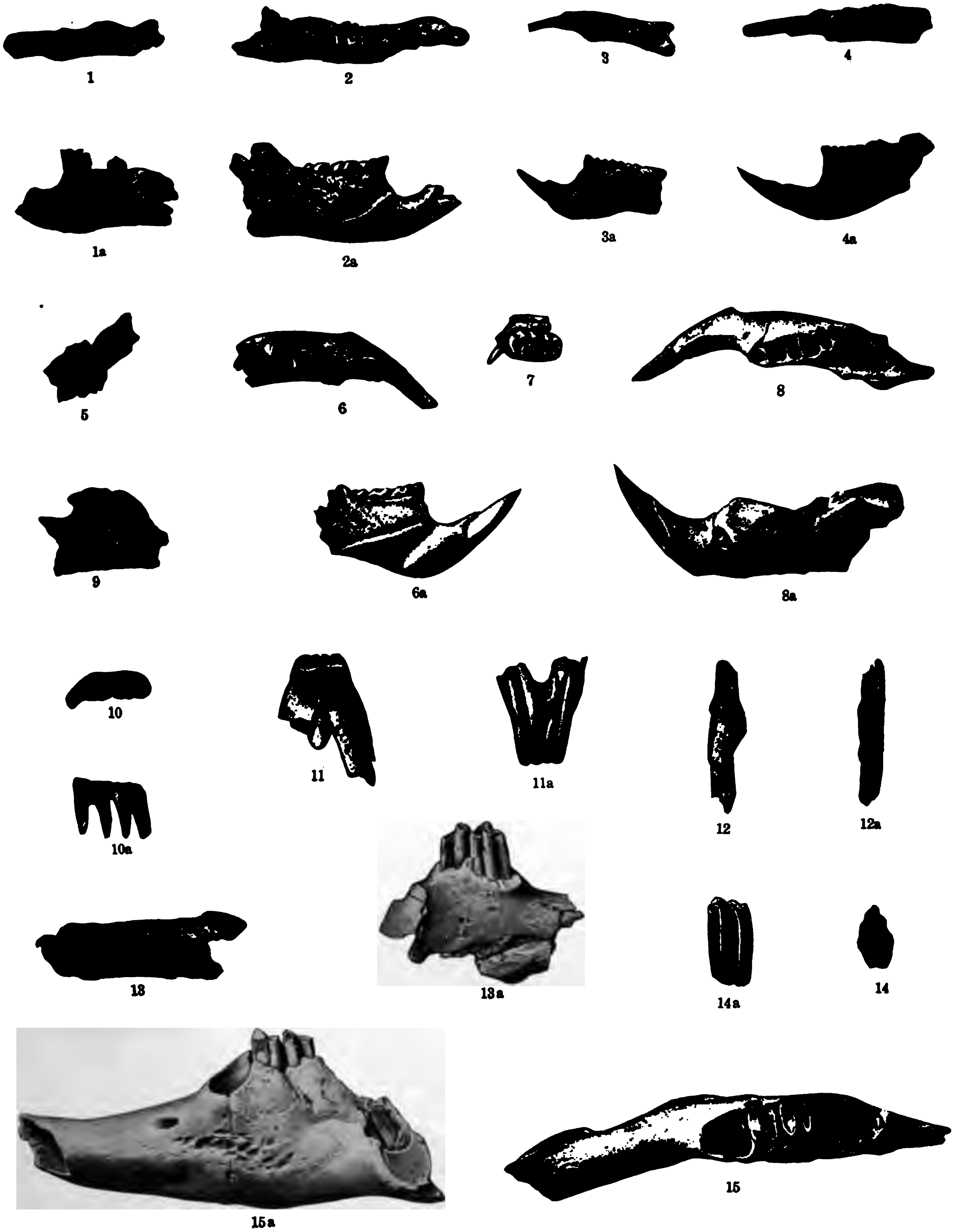


FOSSIL VERTEBRATES OF SAN PEDRO VALLEY, ARIZ.



FOSSIL VERTEBRATES OF SAN PEDRO VALLEY, ARIZ.

PLATE XXXV.

[All figures about twice natural size.]

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REVISION OF THE FLORA OF THE GREEN RIVER FORMATION, WITH DESCRIPTIONS OF NEW SPECIES.

By F. H. Knowlton.

THE GREEN RIVER FORMATION.

The Green River shales, later known as the Green River formation, were named and described by F. V. Hayden in 1869.[1] After discussing the coal and lignite beds along the Union Pacific Railroad in western Wyoming, Hayden says:

> A little east of Rock Spring station a new group commences composed of thinly laminated chalky shales, which I have called the Green River shales, because they are best displayed along Green River. They are evidently of purely fresh-water origin and of middle Tertiary age. The layers are nearly horizontal and, as shown in the valley of Green River, present a peculiarly banded appearance. When carefully studied these shales will form one of the most interesting groups in the West. The flora is already very extensive, and the fauna consists of Melanias, Corbulas, and vast quantities of fresh-water fishes. There are also numerous insects and other small undetermined fossils in the asphaltic slates. One of the marked features of this group is the great amount of combustible or petroleum shales, some portions of which burn with great readiness and have been used for fuel in stoves.

The decade that followed the naming and defining of the Green River shales as a formational unit by Hayden was one of increased geologic study in the West, with the result that these beds were recognized and more or less fully described at a number of widely separated points. Thus Peale[2] recognized the Green River group, as he called it, between Grand (now Colorado) and Gunnison rivers in Colorado; Powell[3] noted it along the northern foothills of the Uinta Mountains, distinguishing a "Lower" and "Upper" Green River; Emmons,[4] who was connected with the Fortieth Parallel Survey, described it very fully for the Green River Basin; Peale[5] found it along the Book Cliffs in western Colorado; White[6] studied it in western Colorado and eastern Utah; Endlich[7] described its occurrence along White River in western Colorado and south of the Wind River Mountains in Wyoming;[8] and Peale[9] noted it in the northern and western parts of the Green River Basin.

One of the most complete of the earlier accounts of the Green River formation is that given by Emmons[10] in his description of the Green River Basin. Three Tertiary formations—or "series," as they were then called—were recognized, the oldest of which was the Wasatch formation (nearly the same as the "Vermillion Creek group" of King and the upper part of the "Bitter Creek series" of Powell). Above this, without apparent discordance, was the Green River formation, which in turn was overlain by the Bridger formation.

The Green River beds were described by Emmons as follows:

> The beds of the Green River series contrast with those of the other two groups by the relative prevalence of calcareous material and the fineness of their sediments. They were deposited in quiet, probably deeper waters and perhaps during the time that erosion was wearing away the limestones of the Upper Coal Measures. They consist of a lower series of calcareous sandstones and impure limestones, containing some lignite seams, overlain by a great thickness of remarkably fissile calcareous shales abounding in remains of fish and insects, which reach an aggregate thickness of about 2,000 feet and are characterized throughout by their prevailing white color. The extent of the sea in which these beds were deposited was somewhat less than that of the previous period, a strip of land having been elevated above its level along the flanks of the Wasatch, and probably also a narrower strip along the shores of the Park Range; its beds, however, were deposited continuously over the ridge of Vermillion Creek Wasatch beds, between the Bitter Creek

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[1] U. S. Geol. Survey Terr. Third Ann. Rept. (reprint, 1873), p. 190.

[2] Peale, A. C., U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1874, pp. 147, 156-158, 1876.

[3] Powell, J. W., Geology of the Uinta Mountains, pp. 40, 45, 166, 167, 1876.

[4] Emmons, S. F., U. S. Expl. 40th Par. Rept., vol. 2, pp. 203, 240, 1877.

[5] Peale, A. C., U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1876, p. 184, 1878.

[6] White, C. A., idem, pp. 19-35.

[7] Endlich, F. M., idem, p. 111.

[8] Idem for 1877, p. 130, 1879.

[9] Peale, A. C., idem, p. 525.

[10] Emmons, S. F., U. S. Expl. 40th Par. Rept., vol. 2, pp. 203, 240, etc., 1877.

[illegible]

It is not within the scope of the present paper to give a complete review of the literature relating to the Green River formation, but simply enough to show its areal distribution and physical characteristics that may serve as a setting for the discussion of its flora and fauna. From data obtained within the first dozen years after it was formally recognized by Hayden and abundantly confirmed by subsequent investigators, the Green River formation is known to extend from the headwater region of Green River, in the Wind River Mountains, Wyo., southward to Grand Mesa, between Colorado and Gunnison rivers, Colo., a distance of approximately 300 miles. The western limit of the formation is rather sharply defined, for it abuts on the eastern foothills of the Wasatch Mountains. The eastern limits, however, are less sharp. Emmons expressed the opinion that the formation originally extended to the western slopes of the Park Range, but the evidence for this opinion is not conclusive. The Green River formation was not recognized by E. E. Smith[11] in his study of the eastern part of the Great Divide coal field, though the Wasatch formation, with thicknesses ranging between 900 and 1,800 feet, is present there, nor was it definitely identified by M. W. Ball[12] in his study of the western part of the Little Snake River coal field, though it may be represented in some undifferentiated beds above the Wasatch formation. The Green River formation is said by A. R. Schultz[13] to extend over the north end of the Rock Springs uplift and out into the Red Desert to a point about 20 miles southeast of the Antelope Hills. It is also present at the south end of the Rock Springs uplift, along the divide between Sage and Red creeks. It thus appears that in all probability these beds once covered a large part of the Great Divide Basin and the Red Desert but were later removed by erosion. In any event, it seems fairly well established that the maximum width of the area once covered in whole or in part by the Green River formation was little if any less than 150 miles.

As already mentioned, Powell divided the Green River formation into a "Lower Green River" and an "Upper Green River." The latest report in which these beds are discussed is that by A. R. Schultz[14] on the area around the Rock Springs uplift in Sweetwater County, Wyo. Schultz recognizes four members of the Green River formation, which in ascending order are as follows: (1) Tipton shale member, consisting of fissile shale, conglomerate, oolitic limestone, shale, clay, and sandstone; (2) Cathedral Bluffs red-beds member, composed of red or varicolored conglomeratic sandstone, shale, and clay; (3) Laney shale member, made up of white and green fissile shale, limestone, and sandstone, "similar to those so characteristic of the lower member or Tipton shale of the Green River in this part of the field and to the entire Green River formation in other parts of the Green River Basin;" (4) "Tower sandstone" and plant beds of Powell, which consist of massive, regularly bedded sandstone, sandy limestone, and shale.

Just how far these proposed subdivisions of the Green River formation can be recognized in other parts of the vast area over which it extends is not now known, though some subdivision is undoubtedly possible. The earliest known and most thoroughly exploited of the plant-bearing beds are along the Union Pacific Railroad 2 or 3 miles west of the town of Green River, where, according to Hayden, Ward, and others, they occur about 100 feet above the fish beds. This places their position some hundreds of feet below the "Tower sandstone" that is so well exposed at the town of Green River. Powell and others who have followed him seem to be in error in speaking of the plant beds as overlying the "Tower sandstone."

It seems rather remarkable, in view of the thickness and areal extent of the Green River formation, that it has been found to be fossiliferous at so few localities. Endlich remarked on this peculiarity many years ago, pointing out that it was possible to follow these beds for miles without finding a trace of animal or plant life. There is such an area north of Rock Springs, Wyo., where beds hundreds of feet in thickness are seemingly well fitted to preserve any forms of life that may have been present in the region, and yet so far as known they are absolutely barren of fossils. The suggestion that these beds may have been deposited in deep water far from shore does not fully explain their barrenness, for even if they were it would seem that they should contain a few specimens.

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[11] U. S. Geol. Survey Bull. 341, p. 230, 1909.

[12] Idem, p. 244.

[13] U. S. Geol. Survey Bull. 702, p. 24, 1920.

[14] Idem, pp. 24-31.

So far as now known the first fossil form from the Green River formation to be brought to scientific attention was a small herring-like fish described by Joseph Leidy[15] in 1856, under the name *Clupea humilis*, later changed to *Diplomystus humilis*. It was collected by Dr. John Evans, who visited the Rocky Mountain region in 1849 and 1856, from the so-called fish beds near the town of Green River and was the forerunner of thousands of wonderfully preserved fish remains that have since been found.

As already stated, Hayden named the Green River formation in 1869, and at that time he mentioned the presence of "an extensive flora," but it is not a matter of record that he brought actual specimens to Washington. However, Hayden again visited the plant and fish beds near Green River during the summer of 1870, writing as follows:[16]

> About a mile west of the "petrified fish bed" is a cut along the railroad which passes through a moderate thickness of buff chalky limestones, filled with impressions of leaves of deciduous plants.

These plants were submitted to J. S. Newberry, and his preliminary report in the form of a letter was published by Hayden in the report cited. The collection comprised only about half a dozen forms sufficiently well preserved to be capable of identification, and of these he wrote as follows:

> Among them I find two palms, both quite unlike anything before found on this continent. One is a new *Phoenicites*, resembling Heer's *Manicaria formosa;* the other but an imperfect fragment, yet altogether new and strange to me. The most abundant species contained in the collection is a *Magnolia*, allied to *M. tenuinervis* Lesquereux but more elongate and acute; also an oak resembling *Quercus saffordi* of Lesquereux. There is another oak in the collection, a laurel (probably), and fragments of two ferns, too imperfect for determination.

This account of the Green River flora, although relatively unimportant, is so far as known the first one published.

On his way back from the field in 1870 Hayden passed over the old overland stage route, which follows Bitter Creek nearly to its head, crosses the Red Desert, and thence goes through Bridger Pass to the Laramie Plains.

THE OIL SHALE AND ITS MICROSCOPIC FLORA AND THE BEARING OF THE FLORA ON THE ORIGIN OF THE SHALE OIL.

The intensive search for sources of petroleum that is now being prosecuted in many parts of the world has naturally directed renewed attention to the oil shales of the Green River formation, which are known to occur over vast areas in Wyoming, Colorado, and Utah. According to Winchester,[17]

> Approximately 5,500 square miles in northwestern Colorado and northeastern Utah are underlain by beds of oil shale thick enough to mine and apparently rich enough to warrant the development of an industry for the manufacture of shale oil and other products.

Concerning the origin of the shale oil Winchester[18] wrote as follows:

> The Green River formation or that part of it including the oil shales consists of remarkably persistent and thinly bedded shales with some sandstone and at places oolite and limestone. The beds were laid down in fresh water which had an enormous expanse and was deep enough so that wave action had little effect on the sediments. The shale is in most places free from grit and contains an immense amount of vegetable matter; the richer beds show by far the greater amount of such material. Singularly enough, such low plant forms as the blue-green algae are represented in great abundance and in a state of almost perfect preservation. Pollen grains are present which came from coniferous trees which grew on land perhaps at considerable distances from the great inland lake in which the shale was deposited. There is also a vast amount of organic material which is too macerated for identification. Complete insects and excellently preserved dipterous larvae as well as fish scales and even perfect fish skeletons have been found, but in most hand specimens of the shale there is little evidence of other plant life.

The microscopic life, especially plant life, of the Green River oil shale, and its probable bearing on the origin of the oil, were under critical study by the late C. A. Davis, of the U. S. Bureau of Mines, and many valuable data have been accumulated, but his death in 1915 brought the study to a close before much had been recorded. A great number of thin sections and other especially prepared material had been brought together, and a few months more of study would have placed the subject on a firm basis. As it is, the only recorded facts resulting from this study are in the form of the following notes prepared by Davis for Winchester's paper:

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[15] Philadelphia Acad. Nat. Sci. Proc., vol. 8, p. 256, 1856.

[16] Hayden, F. V., U. S. Geol. Survey Wyoming Prelim. Rept., p. 143, 1871.

[17] Winchester, D. E., Oil shale in the United States: Econ. Geology, vol. 13, p. 508, 1917.

[18] Idem, p. 510.

Flora of the oil shale of the Green River formation.

(*a*) Bacteria, *Crenothrix*, and similar low filamentous types.
(*b*) Myophyceae: Blue-green algae.
(*c*) Algae: (1) Protococcaceae: *Protococcus*, *Pediastrum*.
    (2) Conjugatae: *Spirogyra*.
(*d*) Fungi: Saprophytic molds, etc.
(*e*) Mosses: Spores probably from these plants.
(*f*) Pteridophyta: Ferns; annuli from fern sporangia.
(*g*) Spermatophyta:
    (1) Gymnospermae: Pinaceae; pollen of *Picea* and *Pinus*.
    (2) Angiospermae: Pollen and fragments of cells, tissues, etc. Bark cells and residues, small pieces poorly preserved. In addition there are abundant and well-preserved remains which are of good size and of frequent occurrence, which seem to be structureless so far as cellular structures are concerned. However, they have definite and pretty regular forms and, in *Dictyonophora*, definite areas which carry well-marked and characteristic patterns which seem like cells but which show no cell walls. These anomalous forms seem to have been the most abundant organisms in the waters in which the shales were laid down and are evidently vegetables of a low order of development. They are manifestly in place as they grew, since they do not show in pressed down masses but were buried in natural positions, very slowly.

The bearing of this microscopic flora on the origin of the shale oil is further discussed by Davis in notes quoted by Winchester but need not be mentioned here further than to state that the evidence seems to indicate that the oil was produced in place and not by migration from some other source.

GREEN RIVER LAKE.

The Green River lake was a very considerable body of water, as its length from north to south was approximately 300 miles and its width more than 150 miles. It is not known that this maximum extent was reached at any one time, but at some time during its existence its waters spread in one direction or another to these wide-flung limits. It was bordered on the north and west by what are now lofty mountain ranges, though they were then of far less elevation. Its containing barriers on the east and south are less easily recognizable but were apparently certain low-lying Cretaceous and perhaps earlier rocks that were then emergent. It may have extended as far as the western foothills of the Park Range, but this is somewhat uncertain. The lake was almost bisected by what are now the Uinta Mountains, but it is clear that there was a waterway around the east end of the Uinta Range through Brown's Park. Clarence King's conception of the physical conditions that existed in and adjacent to the Green River Basin during early Eocene time was set forth in the volume devoted to the general geology of the region traversed by the Fortieth Parallel Survey under his direction. Among the subjects discussed are the supposed Tertiary lakes in that region.[19] King pointed out that at the end of Cretaceous time "the relative upheaval of the whole Rocky Mountain chain and the west shore of the Cretaceous sea, including the system of the Wahsatch and its northerly extension, resulted in walling in the system of the Colorado River, which then for the first time became an area from which the sea was quite excluded."

The Wasatch and Rocky mountains converge toward the north and join near the present headwaters of Green River, but toward the south they diverge more and more until in southern Colorado and New Mexico they are 500 miles or more apart. It was within the area inclosed by these mountain systems, but more especially in the northern part, largely in what is now the Green River Basin, that King located his succession of Tertiary lakes. The earliest of these lakes, according to his conception, was a great body of fresh water that extended 150 miles north of the 40th parallel and, from some evidence, for 200 miles to the south and was perhaps 150 miles wide. For this lake he proposed the name Ute Lake. According to King it was in the waters of this lake that the great body of sediments were deposited that later constituted the Wasatch formation.

Subsequent study has more or less discredited King's conclusion as to the lacustrine origin of the Wasatch rocks, many observers regarding them as more probably flood-plain deposits. Be this as it may, at the end of Wasatch time there was a subsidence that permitted a wider overflow of impounded waters. It was in this body of water, named Gosiute Lake by King, that the sediments of the Green River formation were laid down. Whatever may be the origin of the Wasatch sediments, all are apparently agreed that the Green River shales are of lacustrine origin. King says:

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[19] King, Clarence, U. S. Geol. Expl. 40th Par. Rept., vol. 1, pp. 444-448, 1878.

> As developed at characteristic localities in the neighborhood of Green River, this group embraces about 2,000 feet of conformable fine-grained rocks, giving general evidence of accumulation in still, rather deep water. The lower 1,200 feet are made up of finely fissile shales and calcareous clays, with some quite fine limestones. Many of the upper shales are strongly bituminous.

The position of the outlet of Green River lake is not known, though it was doubtless somewhere to the south or southwest. It seems not unlikely that it followed approximately the present Colorado River drainage system, as its surplus waters undoubtedly found their way into the Pacific Ocean.

If the deductions to be drawn from the fish fauna have been correctly interpreted the lake was at a comparatively slight elevation above sea level. Data regarding this fauna furnished by Dr. O. P. Hay, of the United States National Museum, show that about 35 fairly well authenticated species of fish are known from the Green River shales. Three families, represented in this fauna by four genera and eight species, have pronounced marine affiliations. Thus the Clupeidae, which include the very large group of herrings, are represented by three genera and six species. The herrings to-day are mainly confined to the ocean, though some ascend rivers to spawn, and a few live in rivers. The sting rays, represented by a fine, clearly defined species (*Heliobatis radians*) in the Green River, are mainly marine, though a few forms live in rivers. A third family is also represented by a single species, the living representatives of which are found in estuaries and rivers of Australia.

From these facts it seems certain that the sea was not far away from the Green River lake or at least was readily accessible. Cope,[20] who described most of the Green River fishes, says:

> True herring, or those with teeth, are chiefly marine, but they run into fresh-water rivers and deposit their spawn in the spring of the year and then return to salt water. The young run down to the sea in autumn and remain there until old enough to spawn. The size of the fry of the Rocky Mountain herring indicates that they had not long left the spawning ground, while the abundance of adults suggests that they were not far from salt water, their native element. To believe, then, that the locality from which these specimens were taken was neither far from fresh nor far from salt waters is reasonable.

Osborn in discussing the Green River fishes in his "Age of mammals," says in part:

> A large part of the teliosts are related to fishes at present confined to the Eastern Hemisphere. Thus the diplomystids ("rough-backed herrings") survive only in certain rivers and along portions of the coasts of Chile and eastern Australia.

The distance from the Green River lake to the ocean can only be approximated, though it must have been some hundreds of miles. This distance, however, would not have been a serious obstacle to the passsage of fish from one to the other, provided, of course, there were no insurmountable falls or other obstructions in the stream. Salmon are known to ascend to the upper waters of the Yukon to spawn, a distance of 2,250 miles.

About a dozen species of land and freshwater invertebrates (*Helix*, *Physa*, *Viviparus*, *Pupa*, *Unio*, and others) have been found in the Green River shales, but they throw little light on the ecologic conditions that prevailed at that time.

FOSSIL LOCALITIES AND LISTS OF SPECIES.

Locality unknown.—Under the heading "hard, shaly, fine-grained whitish sandstone," Lesquereux[21] enumerated the species listed below and continued:

> About the same consistence and color as the specimens from Carbon station. The precise locality is unknown, the labels having been lost or forgotten.

However, in Lesquereux's "Tertiary flora"[22] all these species are referred without question to the Green River formation.

Cyperus chavannesi Heer.
Populus arctica Heer.
Ficus multinervis Heer.
Ficus lanceolata Heer.
Ficus arenacea n. sp.
Ficus gaudini n. sp.
Platanus sp.
Cinnamomum sp.

These species of *Ficus* have been subsequently identified only in older rocks, such as the Mesaverde and "Laramie." There is absolutely no warrant for calling them Green River, and they are consequently dropped from this flora.

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[20] Cope, E. D., U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1870, p. 431, 1871.

[21] Lesquereux, Leo, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1871, pp. 300, 301, 1872.

[22] U. S. Geol. Survey Terr. Rept., vol. 7, pp. 194, 195, 1878.

Alkali stage station, Wyo.—In 1874 Lesquereux[23] described the following species from Alkali stage station, on the Sweetwater road, about 30 miles north of Green River station on the Union Pacific Railroad:

Alnites unequilateralis n. sp.
Juglans alkalina n. sp.
Carpites viburni n. sp.

Lesquereux was uncertain as to the age of these species but finally concluded that they were probably of the same age as the plant beds at Black Buttes, Wyo. Although the locality has not been revisited it has usually been classed as of Green River age.

Mouth of White River and west of Green River station, Wyo.—In 1874, under the caption "New species of Tertiary fossil plants briefly described," Lesquereux[24] enumerated the following Green River species:

1. Lygodium dentoni n. sp.
2. Myrica ludwigii Schimper.
3. Quercus haidingeri Ettingshausen.
4. Ficus wyomingiana n. sp.
5. Cissus parrottiaefolia n. sp.
6. Phaseolites juglandinus? Heer.
7. Leguminosites alternans n. sp.
8. Sapindus dentoni n. sp.
9. Lomatia microphylla n. sp.

Nos. 1, 2, 6, 7, 8, and 9 were collected by William Denton at the mouth of White River, which empties into Green River. Nos. 3, 4, and 5 were found west of Green River station.

Green River station, Wyo.—In 1872 Lesquereux[25] published a paper entitled "An enumeration with descriptions of some Tertiary fossil plants from specimens procured in the explorations of Dr. F. V. Hayden, in 1870." Under the caption "Green River, above the fish beds," he enumerated the following forms:

Hemitelites torelli Heer?
Arundo göpperti Münster.
Phragmites oeningensis Al. Braun.
Juncus sp.
Salix angusta Al. Braun.
Salix media Al. Braun.
Salix sp.
Myrica nigricans n. sp.
Myrica salicina Unger.
Quercus lonchitis Unger.
Ficus populina Heer.
Ficus ungeri n. sp.
Cinnamomum scheuchzeri Heer.
Eucalyptus americanus n. sp.
Ampelopsis tertiaria n. sp.
Ilex affinis n. sp.
Ilex stenophylla Unger. [Excluded.]
Ceanothus cinnamomoides Lesquereux.
Rhus acuminata n. sp.
Juglans schimperi n. sp.
Juglans acuminata Heer?
Juglans denticulata Heer?

In the same year, under the caption "Green River group, high on hills from river," Lesquereux enumerated the following species:

Ceanothus cinnamomoides Lesquereux.
Carya heerii Ettingshausen.

In the "Tertiary flora" (p. 277) Lesquereux states that *Ceanothus* (or *Zizyphus*) *cinnamomoides* came from "Green River station, Wyo., above the fish beds with *Ampelopsis tertiaria.*" It was collected by F. V. Hayden and is preserved in the United States National Museum (No. 431).

Bridger Pass (?) *and Washakie station, Wyo.*—In the "Tertiary flora" Lesquereux enumerates three species as having come from Bridger Pass, Wyo., as follows:

Laurus utahensis Lesquereux (p. 216).
Aralia? gracilis (Lesquereux) Lesquereux (p. 236).
Rhamnus intermedius Lesquereux (p. 282).

On referring to the place of original description it appears that *Aralia? gracilis* (or *Liquidambar gracile*, as it was first called) and *Rhamnus intermedius* are recorded by Lesquereux[26] as having come from "Washakie station, near Bridger Pass." *Laurus utahensis* was described as new in the "Tertiary flora" and was said to have come from Bridger Pass, "in connection with *Araliopsis* [error for *Aralia*] *gracilis* and *Populus arctica.*" Both these species are found at Washakie station, and with little doubt the species of *Laurus* was also found there.

From this evidence it seems reasonably certain that the three species above mentioned did not come from Bridger Pass, but from Washakie station, which is about 12 miles west of Bridger Pass. The improbability of their having come from Bridger Pass is further emphasized by the fact that, according to Ball,[27] the rocks in the pass are referred to the Mesaverde. On the other hand, Washakie station is in an area in Ball's "upper coal group," which includes "Upper Laramie," Fort Union, and basal Wasatch. As there is no indication by Lesquereux, or by Hayden, who collected these plants, as to where they came in the local section, it is absolutely impossible to place them until they are again collected from beds of known position. To refer them to the Green River formation is not warranted, and, at least for the present, they are excluded from this flora.

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[23] Lesquereux, Leo, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1874, pp. 307, 308, 1876.

[24] Idem, pp. 308-315; also U. S. Geol. and Geog. Survey Terr. Bull., 2d ser., No. 5, pp. 382-389, Jan. 8, 1876.

[25] U. S. Geol. Survey Terr. Fifth Ann. Rept., for 1871, Suppl., pp. 5-9, 22, 1872.

[26] Lesquereux, Leo, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1871, p. 286, 1872.

Green River, Wyo. (plants described by J. S. Newberry).—In 1883 Newberry[28] named and gave preliminary descriptions of the following species:

Acrostichum hesperium.
Pecopteris (Phegopteris) sepulta.
Sabal powellii.
Manicaria haydenii.
Quercus castanoides.
Juglans dentata.
Juglans occidentalis.
Planera variabilis.
Planera nervosa.
Zizyphus longifolia.
Aralia macrophylla.

In 1898 Newberry[29] described and figured the plants enumerated in the preceding paper under the following names:

Lygodium kaulfussii.
Acrostichum hesperium.
Pecopteris (Cheilanthes) sepulta.
Equisetum wyomingense.
Sabal powellii.
Manicaria haydenii.
Juglans occidentalis.
Salix angusta?
Quercus castanoides.
Planera nervosa.
Planera variabilis.
Zizyphus longifolia.
Aralia macrophylla.
Nordenskioldia borealis.

Colorado localities (collections of D. E. Winchester).—The collections of D. E. Winchester include the species listed below.

Yellow sandstone of "Upper Green River," on Greasewood Creek, 40 miles west of Meeker, Rio Blanco County, Colo. (Winchester 7379):

Aralia wyomingensis Knowlton and Cockerell.

Green River oil shale, Cathedral Bluff, Little Tommies Draw, 20 miles west of Rio Blanco post office, Rio Blanco County, Colo. (Winchester 7399):

Caenomyces eucalpytae n. sp.
Myrica sp.
Pimelea spatulata n. sp.
Sedum? hesperium n. sp.
Eucalyptus? americanus Lesquereux.
Carpites inquirenda n. sp.

Green River oil shale, Greasewood Creek, 40 miles southwest of Meeker, Rio Blanco County, Colo. (Winchester 7381):

Caenomyces sp.
Danaea coloradensis n. sp.
Pontederites hesperia n. sp.
Salix sp.
Myrica minuta n. sp.
Myrica praedrymeja n. sp.
Comptonia? anomala n. sp.
Oreodaphne viridiflumensis n. sp.
Sapindus winchesteri n. sp.
Rhus n. sp.
Zizyphus longifolia Newberry.
Sambucus? winchesteri n. sp.
Carpolithes caryophylloides n. sp.

Green River oil shale, Little Duck Creek, 50 miles southwest of Meeker, Rio Blanco County, Colo. (Winchester 7381a):

Dalbergia retusa n. sp.
Sophora coloradensis n. sp.
Mimosites coloradensis n. sp.

Green River oil shale, Cathedral Bluff, 20 miles west of Rio Blanco post office, Rio Blanco County, Colo., in sec. 33, T. 4 S., R. 100 W. (Winchester 7382):

Lygodium kaulfussii Heer.
Salix linearis n. sp.
Salix longiacuminata n. sp.
Juglans winchesteri n. sp.
Dalbergia viridiflumensis n. sp.
Eucalyptus? americana Lesquereux.
Phyllites winchesteri n. sp.

Green River oil shale, Camp Gulch, 25 miles northwest of De Beque, Colo. (Winchester 7384):

Achaenites cichorioides n. sp.

Green River oil shale, head of trail up ridge between Carr and Bushy creeks, 25 miles northwest of De Beque, Colo. (Winchester 7386):

Eucalyptus? americana Lesquereux.

Green River oil shale, head of Carr Creek, 30 miles northwest of De Beque, Colo. (Winchester 7387):

Myrica sp.

SPECIES EXCLUDED FROM GREEN RIVER FLORA.

The following species have been dropped from the Green River flora for the reasons stated:

Acer sp. Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1871, p. 286, 1872.

From Barrel Springs, Wyo.; not afterward recognized by Lesquereux.

Aralia gracilis (Lesquereux) Lesquereux, U. S. Geol. Survey Terr. Rept., vol. 7 (Tertiary flora), p. 236, pl. 39, fig. 1, 18, 78.

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[27] Ball, M. W., U. S. Geol. Survey Bull. 341, pl. 13, 1909.

[28] U. S. Nat. Mus. Proc., vol. 5, pp. 502-514, 1883.

[29] Later extinct floras of North America: U. S. Geol. Survey Mon. 35, 1898.

Liquidambar gracile Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1871, p. 287, 1872.

From Bridger Pass, Wyo., hence excluded. (See p. 138.)

Arundo göpperti Münster. Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1871, Suppl., p. 5, 1872; U. S. Geol. Survey Terr. Rept., vol. 7 (Tertiary flora), p. 86, pl. 8, figs. 3–5.

This species is rejected from the Green River flora and probably should not be recognized in North America. In the "Tertiary flora" Lesquereux figured three specimens that he referred to this species. Of these only one, the original of his Plate VIII, figure 3, is now preserved in the United States National Museum (No. 95), and is before me. It is fully 8 centimeters wide, nearly three times the size of the largest specimen figured by Heer,[30] and is very unlike Heer's figure in appearance. It is marked with numerous fine longitudinal veins or lines, and at fairly regular intervals, about 1 centimeter apart, are stronger lines or folds. It may be a large leaf of *Cyperacites* or possibly a palm leaf. It is too indefinite to be identified.

Blechnum göpperti Ettingshausen. Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1871, p. 283, 1872.

From Henry's Fork, Utah: not again referred to by Lesquereux.

Carya heerii (Ettingshausen) Heer. Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1871, p. 289, 1872.

Not afterward recognized by Lesquereux.

Cinnamomum scheuchzeri Heer. Lesquereux, U. S. Geol and Geog. Survey Terr. Ann. Rept. for 1871, Suppl., p. 7, 1872.

Concerning this species Lesquereux said: "I refer to this species two leaves of *Cinnamomum*, one of which is contracted above the base, as in some forms of *C. buchi* Heer; the other narrower, like a variety of *C. lanceolata* Heer. Both specimens are incomplete and have the nervation of *C. scheuchzeri*, as represented in many specimens from other localities of our Tertiary." This species was not again alluded to as a member of the Green River flora, and the two leaves were probably transferred to some other species, but of this there is no record; they are not now known to be in existence.

Cyperites deucalionis Heer. Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1871, p. 285, 1872.

From Barrel Springs, Wyo.; not afterward referred to by Lesquereux.

Cyperus braunianus? Heer. Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1871, p. 285, 1872.

From Barrel Springs, Wyo.; not afterward mentioned by Lesquereux.

Cyperus chavanensis Heer. Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1871, p. 300, 1872.

Not from the Green River formation. (See p. 137.)

Equisetum haydenii Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1871, p. 284, 1872; U. S. Geol. Survey Terr. Rept., vol. 7 (Tertiary flora), pl. 6, figs. 2–4. 1878.

Ficus arenacea Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1871, p. 300, 1872.

Not from the Green River formation. (See p. 137.)

Ficus gaudini Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1871, p. 200, 1872.

Not from the Green River formation. (See p. 137.)

Ficus lanceolata Heer. Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1871, p. 300, 1872.

Not from the Green River formation. (See p. 137.)

Ficus multinervis Heer. Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1871, p. 300, 1872.

Not from the Green River formation. (See p. 137.)

Ficus populina Heer, Flora tertiaria Helvetiae, vol. 2, p. 66, pl. 85, figs. 1–7; pl. 86, figs. 1–11, 1856; Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1871, Suppl., p. 6, 1872.

Ficus populina was characterized by Heer from specimens obtained in the Swiss Miocene. A number of leaves from the Green River formation were identified by Lesquereux with Heer's species, although he states that they show "some marked differences," such as being obtuse rather than long and acutely pointed, having the veins nearer the borders, and having the marginal teeth pointed rather than round. There is a great deal of variation in the size and appearance of the forms referred to *Ficus populina* by Heer, and as Lesquereux did not specify the particular forms he regarded as most like those he had from Green River there is no way of telling where he later referred them. This species will have to be excluded from the Green River flora.

Geonomites goldianus (Lesquereux) Lesquereux, U. S. Geol. Survey Terr. Rept., vol. 7 (Tertiary flora), p. 115, pl. 9, fig. 9, 1878.

Wrong identification.

Palmacites goldianus Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1874, p. 311, 1875.

From Barrel Springs, Wyo.

Hemitelites torrelli Heer? Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1871, Suppl., p. 5, 1872.

Not afterward referred to by Lesquereux.

Ilex dissimilis Lesquereux, U. S. Geol. Survey Terr. Rept., vol. 7 (Tertiary flora), p. 271, pl. 50, figs. 7–9, 1878.

This species comes from Sage Creek, Mont., in beds of doubtful age. There seems no longer any valid reason for including this in the Green River formation, even with a question, and it is excluded.

Ilex stenophylla Unger. Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1871, Suppl., p. 8, 1872.

Not afterward mentioned by Lesquereux in connection with the Green River flora.

Juglans acuminata Heer? Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1871, Suppl., p. 8, 1872.

Lesquereux compares his Green River leaf with a peculiar form of *Juglans acuminata* from the Swiss Miocene, but as he did not afterward allude to it in this connection it was probably placed under some other form without record of such transfer.

Juglans dentata Newberry, U. S. Nat. Mus. Proc., vol. 5, p. 507, 1882 [1883].

Although this species was described by Newberry it was evidently merged with some other species in the formal publication of the "Later extinct floras," but just which one can not be determined. Hollick, who edited this work of Newberry's, states that he could find neither specimen, figure, nor manuscript relating to it, so it would best be dropped.

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[30] Heer, Oswald, Flora tertiaria Helvetiae, vol. 1, pl. 23, fig. 1, 1854.

Laurus utahensis Lesquereux, U. S. Geol. Survey Terr. Rept., vol. 7 (Tertiary flora), p. 216, 1878.

Said to have come from Bridger Pass, Wyo., but the locality is uncertain, hence it is best excluded from the Green River flora. (See p. 138.)

Leguminosites lesquereuxiana Knowlton, U. S. Geol. Survey Bull. 152, p. 131, 1898; Mon. 32, pt. 2, p. 730, pl. 79, fig. 4, 1899. [See below.]

Leguminosites cassioides Lesquereux, U. S. Geol. Survey Terr., Rept., vol. 7 (Tertiary flora) p. 300, pl. 59, figs. 1-4, 1878. [Homonym; replaced by *L. lesquereuriana.*]

It seems probable that this species would best be excluded from the Green River flora, for although Lesquereux states that three of the figured types were obtained above the fish beds at Green River, they are not to be found with the other material from this locality that is preserved in the United States National Museum, and their present location is unknown. The other type is from the supposed Livingston formation of the Bozeman coal field, Mont. As this species has not subsequently been found in the Green River formation, it is excluded, at least for the present.

Magnolia sp. Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1871, p. 287, 1872.

This is stated to have come from Washakie station, Wyo., but as it was not afterward referred to by Lesquereux it should be dropped.

Myrica studeri? Heer. Lesquereux, U. S. Nat. Mus. Proc., vol. 10, p. 38, 1887.

The locality for this specimen is supposed to be White River, Wyo., but it is so uncertain and the specimen is so obscure that it is here excluded from the Green River flora.

Phaseolites juglandinus? Heer. Lesquereux, U. S. Geol. and Geog. Survey Terr. Bull., vol. 1, p. 388, 1875 [1876].

Undoubtedly an error for *Phyllites juglandinus* Heer, as no record can be found in Heer of the combination given by Lesquereux. This species was described by Lesquereux from material collected near the mouth of White River, Wyo., but it was not afterward referred to and was probably merged with some other form, without record of its transfer. It is consequently dropped from the Green River flora.

Poacites laevis Al. Braun. Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1871, p. 285, 1872.

From Barrel Springs, Wyo.

Populus arctica Heer. Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1871, p. 300, 1872.

Not from the Green River formation. (See p. 137.)

Quercus lonchitis Unger. Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1871, Suppl., p. 6, 1872.

This species was identified by Lesquereux in a collection of plants from Green River but was never figured and is now lost or merged with some other form; it has not since been identified with American material. It was not mentioned by Lesquereux in the "Tertiary flora."

Rhamnus washakiensis Cockerell, Am. Mus. Nat. Hist. Bull., vol. 24, p. 74, 1908. [See below.]

Rhamnus intermedius Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1871, p. 286, 1872; U. S. Geol. Survey Terr. Rept., vol. 7 (Tertiary flora), p. 282, pl. 54, fig. 3, 1878. [Homonym, Steudel and Hockstetter. 1827; replaced by *R. washakiensis.*]

This species rests on the single type specimen as figured by Lesquereux (U. S. N. M. No. 447). It is a rather nondescript oblong-elliptical leaf, about 6 centimeters long and a little less than 2 centimeters wide, with a strong midrib and about 16 pairs of close, parallel camptodrome secondaries. This species seems to approach most closely *Rhamnus obovatus* Lesquereux,[31] a species of somewhat doubtful age but distinguished by its obovate instead of elliptical outline. More material might bring them closer together, but for the present they are best kept apart.

From Bridger Pass, Wyo., and hence excluded from the Green River flora. (See p. 138.)

Sequoia heerii Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1871, p. 290, 1872; U. S. Geol. Survey Terr. Rept., vol. 7 (Tertiary flora), p. 77, pl. 7, figs. 11-13, 1878.

This species was described as coming from "Sage Creek, Mont.," a locality that has not since been found; hence, of course, its age is in doubt. *Sequoia heerii* has been subsequently identified in the upper part of the Clarno formation of Oregon, the Kenai formation of Alaska, and the Lance formation of Montana and Wyoming. It has not been reported from any Green River locality, and the manner in which it came to be even tentatively accredited to this formation is unknown.

Zanthoxylon juglandinum? Al. Braun. Lesquereux, U. S. Geol. Survey Terr. Rept., vol. 7 (Tertiary flora), p. 294, pl. 58, fig. 10, 1878.

This species comes from Washakie, Wyo., from beds whose position is not definitely settled as in the Green River formation; hence it is excluded.

SYNONYMS AND CHANGES OF NAMES.

Acer indivisum Lesquereux = *Acer lesquereuxii* Knowlton.
Alnites inaequilateralis Lesquereux = *Planera inaequilateralis.*
Alnus inaequilateralis Lesquereux = *Planera inaequilateralis.*
Ampelopsis tertiaria Lesquereux = *Parthenocissus tertiaria.*
Apocynophyllum scudderi Lesquereux = *Eucalyptus? americana.*
Aralia macrophylla Newberry = *Aralia wyomingensis.*
Ceanothus cinnamomoides Lesquereux = *Zizyphus cinnamomoides.*
Juglans denticulata Heer. Lesquereux = *Juglans crossii.*
Juglans occidentalis Newberry (part) = *Carpites newberryana.*
Juglans schimperi Lesquereux (part) = *Juglans occidentalis.*
Lygodium neuropteroides Lesquereux = *Lygodium kaulfussii*
Myrica nigricans Lesquereux = *Rhus nigricans.*
Pecopteris sepulta Newberry = *Osmunda? sepulta.*
Planera variabilis Newberry (part) = *Planera inaequilateralis.*

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[31] Lesquereux, Leo, U. S. Geol. Survey Terr. Rept., vol. 7 (Tertiary flora), p 281, pl. 54, figs. 1, 2, 1878.

Quercus castaneoides Newberry=*Quercus castaneopsis.*
Rhus acuminata Lesquereux=*Rhus lesquereuxii* Knowlton and Cockerell.
Salix angusta Al. Braun? Newberry=*Eucalyptus? americana.*
Salix media Heer. Lesquereux, U. S. Geol and Geog. Survey Terr. Ann. Rept. for 1871, Suppl., p. 6, 1872=*Salix* sp.
Spheria myricae Lesquereux=*Sphaerites myricae.*
Zizyphus longifolia Newberry (part)=*Zizyphus cinnamomoides.*

THE ACCEPTED GREEN RIVER FLORA.

The Green River flora as here described comprises the following species:

Caenomyces eucalyptae Knowlton, n. sp.
Caenomyces sapindicola Knowlton, n. sp.
Sphaerites myricae (Lesquereux) Meschinelli.
Acrostichum hesperium Newberry.
Lygodium kaulfussii Heer.
Lygodium dentoni Lesquereux.
Osmunda? sepulta (Newberry) Knowlton.
Danaea coloradensis Knowlton, n. sp.
Equisetum wyomingense Lesquereux.
Arundo reperta Lesquereux.
Cyperus chavannesi Heer.
Cyperacites haydenii (Lesquereux) Knowlton.
Geonomites haydenii (Newberry) Knowlton, n. comb.
Sabal powellii Newberry.
Flabellaria florissanti Lesquereux.
Pontederites hesperia Knowlton, n. sp.
Juncus sp. Lesquereux.
Musophyllum complicatum Lesquereux.
Salix linearis Knowlton, n. sp.
Salix longiacuminata Knowlton, n. sp.
Salix sp. Knowlton.
Salix sp. Knowlton.
Myrica salicina Unger.
Myrica minuta Knowlton, n. sp.
Myrica praedrymeja Knowlton, n. sp.
Myrica ludwigii Schimper.
Myrica sp. Knowlton.
Myrica sp. Knowlton.
Comptonia? anomata Knowlton, n. sp.
Juglans occidentalis Newberry.
Juglans schimperi Lesquereux.
Juglans crossii Knowlton.
Juglans alkalina Lesquereux.
Juglans winchesteri Knowlton, n. sp.
Quercus castaneopsis Lesquereux.
Planera inaequilateralis (Lesquereux) Knowlton, n. comb.
Ficus ungeri Lesquereux.
Ficus wyomingiana Lesquereux.
Ficus tenuinervis Lesquereux.
Lomatia? microphylla Lesquereux.
Oreodaphne viridiflumensis Knowlton, n. sp.
Pimelea spatulata Knowlton, n. sp.
Brasenia? antiqua Newberry.
Sedum? hesperium Knowlton, n. sp.
Amygdalus gracilis Lesquereux.
Dalbergia viridiflumensis Knowlton, n. sp.
Dalbergia retusa Knowlton, n. sp.
Leguminosites alternans Lesquereux.
Sophora coloradensis Knowlton, n. sp.
Mimosites coloradensis Knowlton, n. sp.
Ailanthus longe-petiolata Lesquereux.
Sapindus dentoni Lesquereux.
Sapindus obtusifolius Lesquereux.
Sapindus winchesteri Knowlton, n. sp.
Rhus lesquereuxii Knowlton and Cockerell.
Rhus variabilis (Newberry) Knowlton, n. comb.
Rhus nigricans (Lesquereux) Knowlton, n. comb.
Rhus myricoides Knowlton, n. sp.
Euonymus flexifolius Lesquereux.
Acer lesquereuxii Knowlton.
Ilex? affinis Lesquereux.
Ilex maculata Lesquereux.
Ilex wyomingiana Lesquereux.
Zizyphus longifolia Newberry.
Zizyphus cinnamomoides (Lesquereux) Lesquereux.
Cissus parrottiaefolia Lesquereux.
Parthenocissus tertiaria (Lesquereux) Knowlton, n. comb.
Eucalyptus? americanus Lesquereux.
Aralia wyomingensis Knowlton and Cockerell.
Andromeda delicatula Lesquereux.
Sambucus? winchesteri Knowlton, n. sp.
Achaenites cichorioides Knowlton, n. sp.
Antholithes improbus Lesquereux.
Carpolithus caryophylloides Knowlton, n. sp.
Carpites viburni Lesquereux.
Carpites newberryana Knowlton, n. sp.
Carpites inquirenda Knowlton, n. sp.
Phyllites winchesteri Knowlton, n. sp.
Phyllites fremonti Unger.
Phyllites coloradensis Knowlton, n. sp.
Nordenskiöldia borealis Heer.

RELATION OF GREEN RIVER FLORA TO OTHER FLORAS.

The position of the Green River formation above the Wasatch and below the Bridger fixed its stratigraphic horizon as approximately middle Eocene. Hayden when he named the formation made no attempt to fix its position definitely within the Tertiary, though by inference it fell within the Eocene. Cope, who first studied the Green River fish, did not venture more than to place it in the Eocene, because he regarded the available data as insufficient.

Lesquereux,[32] who was the first to study the flora systematically, placed these beds in his so-called fourth group, which comprised a "Lower Green River" and an "Upper Green River." To the first of these he referred the localities of Barrel Springs and Green River station (above fish beds), Wyo., and Sage Creek, Mont., and to the second the localities Florissant, Colo., Elko, Nev., and White River, Wyo.

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[32] Lesquereux, Leo, U. S. Geol. Survey Terr. Rept., vol. 7 (Tertiary flora), pp. 314-326, 1878.

In his final consideration of the Green River flora Lesquereux [33] referred all these localities to the Green River formation. For many years thereafter the Florissant lake beds were generally regarded as of Green River age, but subsequent study had placed them in the upper Miocene. The plants from Elko, Nev., have not been critically studied and revised in recent years, but they are probably slightly younger than the Green River.

As pointed out in another place, the localities of Barrel Springs, Fort Bridger, and Sage Creek have been removed from the Green River formation on the ground of uncertainty as to their position.

The only described middle Eocene flora with which the Green River flora may be compared is one from the so-called Congaree clay member of the McBean formation of the Claiborne group [34] of Georgia, described by Berry.[35] This is a small flora of only 17 species, belonging to the following genera:

Acrostichum.
Arundo.
Castanea.
Conocarpus.
Dodonaea.
Ficus.
Malapoenna.
Mimosites.
Momisia.
Pisonia.
Pistia.
Potamogeton.
Rhizophora.
Sapindus.
Sphaerites.
Terminalia.
Thrinax.

The genera common to these two floras are

Acrostichum.
Arundo.
Ficus.
Mimosites.
Sapindus.
Sphaerites.

Although none of the species are held to be common to the two, there are several that are evidently rather closely related. Thus *Acrostichum georgianum* is regarded by Berry as closely related to *Acrostichum hesperium*, "differing from it in being somewhat more slender in habit and in having straighter midveins and less elongate, finer areolation." *Arundo pseudogoepperti*, although a mere fragment, is regarded as very similar to and possibly identical with *Arundo reperta*, from the Green River. The only species of *Ficus* from the Georgia locality is *Ficus claibornensis*. It is an oblong-lanceolate leaf in which very little of the nervation is preserved and is quite different from either of the Green River species. *Mimosites georgianus* is certainly very similar to *Mimosites coloradensis*. *Sapindus georgiana*, according to Berry, suggests *Sapindus angustifolius* and *S. stellariaefolius*, both from the Florissant lake beds, but is not particularly close to any Green River species. The Georgia species of *Sphaerites* is similar to *Sphaerites myricae* from the Green River, but all fossil leaf-spot fungi are so similar that without the essential organs it is almost impossible to be certain of identifications.

The ecologic conditions under which this Georgia flora grew are discussed at length by Berry, who concludes that it was distinctly a coastal flora. The only forms to which this interpretation would not apply are *Castanea*, which is an upland type, and *Pistia* and *Potamogeton*, both of which are aquatic but not of coastal waters. All these could have been brought down from higher land by a stream. Concerning the others Berry says:

> It is interesting to note that the remaining 12 species are all plants of a coastal habitat, their modern representatives flourishing in the tidal nipa swamps of the Orient, in mangrove swamps of the Orient and Occident, on the strand in beach jungle, or on the landward side of coastal sand dunes. Nearly all are represented by forms found in the existing flora on the Florida keys or along the shores of peninsular Florida, some, like *Conocarpus*, flourishing equally well on either muddy or sandy shores. Every species has representatives in the American Tropics.

The actual physical conditions Berry interprets as follows:

> The present winter isotherm in the latitude of Grovetown [Ga.] is approximately 48° F. None of the closely allied modern plants flourish north of the winter isotherm of 52° F., and most of them do not occur north of the winter isotherm of 60° F. None of the fossil forms except possibly the *Potamogeton*, the modern species of which range over a great many degrees of latitude, or the *Castanea*, which likewise has a wide range, would be expected to occur outside the latitudes where what Schimper calls the subtropical or warm temperate rain forests are found. We would expect the Claiborne climate, at least at low elevations along the coast and in proximity to the warm Eocene ocean current or currents, to have been uniformly humid, with an annual rainfall somewhere between 150

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[33] U. S. Geol. Survey Terr. Rept., vol. 8 (Cretaceous and Tertiary floras), pp. 206-218, 1883.

[34] Later more detailed work revealed the fact that the deposits from which this flora was collected are of Jackson (upper Eocene) age and belong to the Twiggs clay member of the Barnwell formation. See U. S. Geol. Survey Prof. Paper 120, pp. 41-77, 1919.

[35] Berry, E. W., The Upper Cretaceous and Eocene floras of South Carolina and Georgia: U. S. Geol. Survey Prof. Paper 84, pp. 129-163, pls. 24-29, 1914.

and 200 centimeters. The actual rainfall could become a more or less negligible factor provided the water table approached close to the surface and the humidity was high and constant. The temperature would have to be uniform rather than hot, judging by modern standards, for any degree of winter cold would have been fatal. The climate need not have been tropical, nor would it be surprising if the Claiborne marine fauna failed to show tropical forms or reef corals, for the main factors which would limit the spread of a flora like the one described would be uniform humidity, ample rainfall, and the absence of severe cold.

As might perhaps be expected, there is comparatively little identity of species between the Green River flora and early Eocene floras. At one time it was thought that there were several "Laramie" species that persisted into the Green River, but as shown in another place this belief was due to a small collection of obviously older forms for which the locality label had been either "lost or forgotten" and which were wrongly placed in the Green River.

According to the books the following species have been found common to the Green River and Fort Union formations:

Lygodium kaulfussii.
Juglans occidentalis.
Quercus castanopsis.
Ficus ungeri.
Zizyphus cinnamomoides.
Andromeda delicatula.

The Fort Union flora, however, is much in need of critical revision, and it is probable that when this revision is made it will be found that some of these species were misidentified.

A single Green River species (*Juglans crossii*) has been reported in the Hanna formation of south-central Wyoming.

So far as known no species has been found common to the Green River flora and those of the Arapahoe, Denver, Raton, or Lance formations. One Green River species (*Rhus affinis*) has been reported from the Wilcox flora, but as Berry seriously questions the identification it can not be considered of much importance. Another Green River species (*Ficus tenuinervis*) has been identified in the lower part of the Clarno formation of Oregon, and another (*Sapindus obtusifolius*) in the Mascall (Miocene) formation of Oregon.

Although Lesquereux referred the Florissant lake beds to the Green River formation, the present revision has shown only one species (*Amygdalus gracilis*) as common to the two, and even this is open to some question.

BIOLOGIC AND ECOLOGIC INTERPRETATION OF THE FLORA.

Although the known flora of the Green River formation is still rather small, it includes a number of species that are of considerable biologic interest, and it is perhaps large enough to permit the drawing of at least tentative conclusions regarding the climatic conditions under which it flourished. As already pointed out, the great bulk of the formation is almost if not entirely unfossiliferous, but where any fossils occur in it they are generally very abundant. Thus, the so-called fish beds near the town of Green River have yielded many thousands of fish remains, as many as a hundred occurring on a small slab. In some layers—for example, in the layers just above the fish beds that contain the remains of palms—the plant remains are so matted together as to be individually indistinguishable. In southwestern Colorado the fossiliferous beds associated with the oil shale contain a profusion of plant and insect remains. As already stated, the study of the microscopic flora of the oil shale has been only partly completed, though sufficient to show the presence of bacteria, blue-green algae, *Protococcus*, *Spirogyra*, saprophytic fungi, mosses, ferns, and various types of seed-bearing plants. Some of these—perhaps all of them—but particularly the algae appear to have contributed to the accumulation of the oil in the shale. The algae are said to occur in great abundance and in a very perfect state of preservation, which would imply warm, rather shallow water. The great mass of amorphous undifferentiated vegetable matter in the oil shale indicates the action of bacteria in its reduction, which could hardly have taken place at depths much exceeding 20 feet. There is little evidence of the presence of moss plants, and the presence of spores must have been more or less fortuitous, for the mosses are plants so small and inconsequential that their spores could hardly have been much of a factor. The moss spores, the spores and sporangia of ferns, and the pollen of conifers must have been blown from adjacent land, and hence they give no indication of the depth of water in which they fell, nor of the temperature at which they grew, for it is not possible from available data to identify the types of plants that produced them.

Turning now to the plants described in this paper, we have at least three distinct forms of leaf-spot fungi, occurring on three types of leaves—*Myrica*, *Sapindus*, and *Eucalyptus*. They have the same general appearance as many present-day leaf-spot fungi, but as their spore characters can not be made out their systematic position is subject to more or less question. Their requirements as to temperature are, of course, the same as that of the leaves on which they grew.

The ferns of the Green River formation are represented by five well-marked forms, some of which are of exceptional interest. Thus *Danaea*, although described from a fragment, is perfectly authenticated and so far as known is the first example of the living type to be found fossil. This genus comprises more than 25 living species, all strictly American, ranging from Cuba and southern Mexico to Brazil. They are terrestrial ferns of rather coarse habit, mostly 2 or 3 feet in height, growing in the shade in moist but well-drained tropical valleys and slopes, where the humidity is high and constant. The fossil form seems to be most clearly related to a species living on the island of Trinidad. Another rather striking Green River fern is *Acrostichum*, which has only three living species living in tropical tidal marshes in both old and new worlds. Climbing ferns of the genus *Lygodium* are represented by two nominal species in the Green River flora. The better known of these is identified as *Lygodium kaulfussii*, a form first described from specimens obtained in the Miocene of Thuringia but since widely known from collections in Europe and this country. The genus is a large one distributed mainly in the Tropics of both hemispheres, especially in coastal thickets. The remaining fern of the Green River flora is referred with question to the genus *Osmunda*.

The Equisetacae are represented by a single species of *Equisetum* that is poorly preserved and can not be of much value in the present connection.

With the exception of some pollen grains found in connection with the oil shale, no remains of conifers have been reported from the Green River formation.

The monocotyledons are better represented, though there is nothing very remarkable. There are the usual nondescript forms referred to *Arundo*, *Cyperus*, and *Cyperacites*, with a doubtful species of *Juncus*. The most impressive things are the palms, of which there are three nominal forms referred to different genera, though more complete material may change certain of these references. The species of *Geonomites* and *Sabal* are very rare—in fact, are known only from the type material—but the form referred to *Flabellaria* was very abundant at one locality and of large size. The leaves are so matted together that it is impossible to get them out whole, but from many fragments studied the conviction grows that they must have been at least 4 or 5 feet in diameter. They had a long, rather slender, unarmed petiole.

The family Palmaceae, which comprises about 150 genera and 1,000 species, is essentially tropical and about equally distributed in the Eastern and Western hemispheres. At the present time the highest northern latitude it reaches in Europe is about 43° and the highest southern latitude about 45° in New Zealand. A few species extend their range into temperate regions, and some can even endure a temperature below 32°, but they are the exception.

Palms were introduced at least as early as middle Cretaceous time and during the early part of the Tertiary period had attained a wide range, occurring, for instance, in Grinnell Land, Spitzbergen (80° north), in Greenland (70°), and in this country in Fort Union beds near the mouth of the Yellowstone, in the Puget group of Oregon and Washington, in the Kenai formation and other Eocene beds of Alaska, in the Denver and Raton formations of eastern Colorado and northeastern New Mexico, and in the Wilcox group of the Gulf region.

The two remaining monocotyledons are *Musophyllum*, based on large but fragmentary *Musa*-like leaves that may or may not be correctly referred to the Musaceae, and *Pontederites*, a newly described form that seems correctly interpreted as ancestral to the genus *Pontederia*. The Pontederiaceae are a small American family of 5 genera and about 25 species living in warm and temperate regions. *Pontederia* is a variable aggregation, by some regarded as a single species; others recognize two species, one confined to North America and one to South America; but the latest view inclines to the recognition of seven or eight species. The North American species (*Pon-*

tederia cordata Linné), the well-known pickerel weed, ranges from Nova Scotia to Minnesota and south to Florida and Texas. It grows in shallow fresh water. The leaf of the Green River form is certainly very similar to the living form.

The Salicales are represented in this flora by four forms of *Salix*, two of which are so fragmentary that they have not been given specific names. The others are small, narrow, rather nondescript leaves that it is difficult to place satisfactorily. They appear to be willow leaves, but their affinities are more or less doubtful. Hence any conclusions as to their ecologic conditions must be more or less tentative.

The Myricales are represented by six forms of *Myrica* and a single anomalous and more or less doubtful leaf referred to *Comptonia*. The five species of *Juglans* representing the Juglandaceae are not particularly noteworthy, nor is the single species of *Quercus* which represents the Fagaceae. The single species of *Planera*, of the family Ulmaceae, was a very abundant plant in the Green River and seems to be very well authenticated. The three species of *Ficus* representing the Moraceae were not apparently very numerous, but one (*Ficus ungeri*) had large, fine leaves. The Proteaceae are questionably represented by a single species of *Lomatia*. The type specimens are lost, and the generic reference is more than doubtful. They might be leaflets of some mimosaceous or *Sapindus*-like form. To the Lauraceae are referred two genera (*Oreodaphne* and *Pimelea*), each with a single species and each based on a single specimen. The species of *Pimelea* is rather closely related to a species from the Florissant lake beds. The species of *Brasenia*, the sole representative of the Nymphaeaceae, seems well authenticated. *Brasenia* is a monotypic genus of aquatic perennial plants found in North America, Cuba, eastern and tropical Asia, western tropical Africa, and Australia. The Crassulaceae are doubtfully represented by a species referred with question to *Sedum*, but the resemblance may be only superficial. The single species of *Amygdalus* is involved in so much doubt that it is hardly worth while discussing its affinities. The Papilionaceae are represented by two species of *Dalbergia* and one each of *Sophora* and *Leguminosites*, and the Mimosaceae by one species of *Mimosites*. These are all small, narrow leaves or leaflets and if correctly identified would seem to indicate a moist lowland habitat. The living species of these genera are very numerous and are widely scattered over the warmer parts of both hemispheres, being especially abundant on all tropical seashores. In the order Geraniales the Simarubaceae are represented by a very well authenticated species of *Ailanthus*, though the connection between the leaf and the winged fruit may be uncertain. *Ailanthus* is not now a native of the Western Hemisphere, the seven living species being confined to eastern Asia and the East Indies. They are at home in warm or subtropical temperatures.

The order Sapindales is represented by several families in the Green River flora. Of these the Anacardiaceae claim four species of *Rhus*. This family numbers about 60 genera and 450 living species of trees and shrubs and is present in the Tropics and subtropics of both hemispheres, being specially abundant in Malaysia. *Rhus* is the only genus of the family found outside the Tropics. The Celastraceae are represented by a single species of *Euonymus*. This genus has about 60 living species, widely distributed throughout the Northern Hemisphere, but is most abundant in the Asiatic Tropics and in Japan and China. The Sapindaceae, represented in the Green River by four species of *Sapindus*, constitute a very large family of over 100 genera and 1,000 species. They are mostly confined to tropical or subtropical regions. The Ilicaceae comprise only five genera and less than 200 species. The principal genus is *Ilex*, which is found in nearly all tropical and temperate regions and is represented in the Green River flora by three species. In the order Rhamnales the family Rhamnaceae includes about 50 genera and 500 living forms, mainly of the Tropics but a few, among them *Rhamnus*, extending into temperate regions. The only genus of this family represented in the Green River flora is *Zizyphus*, with two well-marked species. There are about 40 living species of *Zizyphus*, mainly shrubs or small trees, of warm temperate regions, with a few in the Tropics of both hemispheres. The Vitaceae comprise about a dozen genera and nearly 500 species, mainly tropical or subtropical, though a few, such as *Vitis*, extend into temperate regions. *Cissus* is the largest genus, including 250 species, all or nearly all tropical. Inasmuch as the *Eucalyptus* in the Green River flora is questioned there is perhaps no necessity for going further into the history of this family. The final family that needs to be considered is the Araliaceae, represented in the Green River flora by a very well-defined species of *Aralia*. This family embraces about 50 genera and over 500 species, mainly tropical, but a considerable number extend into temperate regions, especially in North America and eastern Asia.

The remaining forms are referred to the genera *Antholithes*, *Carpolithus*, *Carpites*, *Phyllites*, and *Achaenites* and need not be further discussed. The species of *Achaenites* is noteworthy in that it appears to indicate with much certainty the presence of the great group of Compositae.

From the foregoing account it appears that an overwhelming preponderance of the living forms in the families represented in the Green River flora are inhabitants of tropical or subtropical regions, many of them in both hemispheres, yet a considerable number include either genera or species that extend into temperate regions. There is some evidence to show that there were at least two ecologic provinces in Green River time. Thus, there are a number of the genera that are of the lowland type, such as

Lygodium
Acrostichum
Danaea
Osmunda
Arundo
Cyperus
Geonomites
Sabal
Flabellaria
Pontederites
Musophyllum
Planera
Ficus
Lomatia
Pimelea
Oreodaphne
Dalbergia
Leguminosites
Sophora
Mimosites
Ailanthus
Sapindus
Eucalyptus?
Aralia
Brasenia

There are other genera that seem to find a more congenial home on higher ground. These are

Salix
Myrica
Comptonia?
Juglans
Quercus
Rhus
Acer?
Zizyphus
Ilex
Andromeda
Sambucus?

This division is not a very satisfactory one, and the assignments may not all be valid, but there were evidently some differences in the conditions under which the several elements were found. The physical setting can be pictured somewhat as follows: About the shores of the lake were certain flat, low-lying areas, some of them probably swampy, others sandy, whereon grew the palms, figs, *Lomatia*, *Oreodaphne*, hackberries, the several papilionaceous trees and shrubs, the ferns, grass, sedge, etc., and in the water the pickerel weed, *Brasenia*, algae, etc. On the adjacent somewhat higher land might have been the willows, waxberries, sweet fern, walnuts, oaks, sumacs, maples(?), hollies, etc.

The conditions of temperature and moisture under which the Green River flora flourished are somewhat difficult of interpretation, as there is seemingly more or less conflict between the elements of the flora. The nearest living relatives of certain of the genera that are believed to have inhabited the lowlands, such as *Lygodium*, *Acrostichum*, *Danaea*, *Geonomites*, *Sabal*, *Flabellaria*, *Musophyllum*, *Planera*, *Ficus*, *Lomatia*, *Pimelea*, *Oreodaphne*, the leguminous genera, and possibly *Sapindus*, *Eucalyptus*, and *Aralia*, are found mainly in subtropical or tropical areas. The palms, at least one species of which existed in abundance, could hardly have lived where the temperature fell below 42° F. and probably not even where it was considerably higher than this. Certain of the other genera, such as *Osmunda*, *Arundo*, *Cyperus*, *Aralia*, and *Brasenia*, might have withstood frost, for although the species of these genera are largely tropical or subtropical they include species that extend into temperate regions. All things considered it seems probable that this lowland flora must have required a temperature that was at least warm temperate and possibly bordered on subtropical.

The upland flora, including such genera as *Salix*, *Myrica*, *Juglans*, *Quercus*, *Rhus*, *Acer*, and *Ilex*, could well have withstood some degree of frost, but on the other hand all these genera contain species that could find a congenial habitat in a warm temperate region. It is doubtful if any of them had to withstand cutting frosts.

The inferences to be drawn regarding the climatic requirements of the insect fauna are in substantial accord with those suggested by the flora. I am informed by Prof. T. D. A. Cockerell that the known insect fauna of the Green River shales now numbers 296 species. Concerning this fauna he says:

> The really dominant and characteristic insects of the Green River shales, if any such can be specially designated, are the Fulgoridae, which have a most distinctly tropical aspect and in many cases closely resemble living tropical genera. The other groups of insects do not appear tropical, though one of the dragon-fly genera is closely related to a neotropical one. The dragon flies, caddis flies, etc., indicate that there was plenty of fresh water, but it does not follow that these breed in the lake.

Alexander,[36] the well-known authority on the crane flies, has the following to say regarding the geologic history of this group:

> The North American Eocene and Miocene, as represented by the White River and Green River beds and the Florissant shales, respectively, give evidence of having had a northern [tipulid] fauna, especially the Eocene. This is well shown by the great development of the Cylindrotominae, which in the White River basin almost dominated the crane-fly fauna during the Eocene. It seems probable, moreover, that the group was forced into colder regions of the globe during the Oligocene, when the tropical element reached far north. No group of crane flies that can be considered tropical has yet been found in the Florissant beds. On the other hand, the European Oligocene, as shown by the Garnet Bay beds and the lower Oligocene Baltic amber, has a considerable tropical element apparent.

From these statements it appears that the evidence of the insects is practically the same as that of the plants, namely, they comprise a certain element that indicates tropical surroundings, and another, or others, that indicate cooler, perhaps temperate conditions.

THE FLORA.

Phylum THALLOPHYTA.

Class FUNGI.

Series ASCOMYCETES.

Order LABOULBILIALES.

Family LABOULBILIACEAE.

Genus CAENOMYCES Berry.

Caenomyces eucalyptae Knowlton, n. sp.

Plate XXXVI, figures 8, 9.

I follow Berry in adopting *Caenomyces* as the generic name of this leaf-spot fungus. Berry's description[37] is as follows:

> The presence of spots of different shapes on the leaves of fossil plants is exceedingly common, and a very large number of so-called species of fossil leaf-spot fungi have been described by Ettingshausen, Heer, Saporta, and others. * * * The identification of these fossil forms obviously rests on a very insecure foundation, especially when it is recalled that scale insects and a great variety of insect galls would resemble epiphyllous fungi when preserved on impressions of fossil leaves. Nevertheless, large numbers of undoubted fungi are preserved in this manner, and it is the legitimate duty of the paleobotanist to describe and illustrate them. In order to accomplish this work without unwarranted definiteness in generic classification, I propose the term *Caenomyces* as a form genus for leaf-spot fungi of Cenozoic age whose precise botanic affinities can not be determined.

One of the leaves of *Eucalyptus? americanus* from western Colorado shows about twenty very well preserved leaf spots, apparently caused by a fungus. They are circular, are about 1.5 or 2 millimeters in diameter, and have an outer black ring perhaps 0.05 millimeter in width under which the substance of the leaf has shrunken. The center of the ring is elevated, and on the top of this in the center are several black pustules evidently where the mature spores are being or about to be discharged.

The disposition and general appearance of these leaf spots is shown in figure 8 natural size, and one of the most perfect spots in figure 9, which is enlarged six times.

Occurrence: Green River formation, on leaf of *Eucalyptus? americanus* Lesquereux, Cathedral Bluff, south of Little Tommies Draw, about 20 miles west of Rio Blanco post office, Rio Blanco County, Colo., collected by D. E. Winchester, 1917.

Caenomyces sapindicola Knowlton, n. sp.

Plate XXXVI, figure 10.

The type leaflet of *Sapindus winchesteri* (Pl. XXXVIII, fig. 1) shows the presence of several leaf-spot fungi. The spots are circular, 1.5 to 2 millimeters in diameter, and some show an inner ring with a slightly raised central portion. It is evidently not mature and is so obscure that it is hardly worthy of mention except to call attention to the presence of fungi of this general type on *Sapindus*.

Occurrence: Green River formation, on type leaflet of *Sapindus winchesteri* Knowlton, oil shale, Smith ranch, on Greasewood Creek, about 40 miles southwest of Meeker, Colo., collected by D. E. Winchester, 1917.

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[36] Alexander, C. P., The crane flies of New York, pt. 2: Cornell Univ. Agr. Exper. Sta. Mem. 38, p. 764, 1920.

[37] Berry, E. W., U. S. Geol. Survey Prof. Paper 91, p. 162, 1916.

Order SPHAERIALES.

Family SPHAERIACEAE.

Sphaerites myricae (Lesquereux) Meschinelli.

Sphaerites myricae (Lesquereux) Meschinelli, Sylloge fungorum fossilium, p. 23, 1892.

Spheria myricae Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1872, p. 390, 1873; U. S. Geol. Survey Terr. Rept., vol. 7 (Tertiary flora), p. 34, pl. 1, fig. 4, 1878.

This species was first described from specimens collected at Black Buttes, Wyo., where it was found on leaves of *Myrica torreyi* Lesquereux. It was later found at Green River, Wyo., on leaves of *Myrica nigricans* (now *Rhus nigricans*).

It was described by Lesquereux as follows: "Perithecia punctiform, minute, either sparse or in a circle, forming round spots" about a millimeter in diameter, "the center of which is clear and of a light color." It may be the same as *Caenomyces eucalyptae*, described on page 148, but as it can not be certainly identified with that species it is permitted to stand as left by Lesquereux.

Occurrence: Green River formation, Green River, Wyo., on leaves of *Myrica nigricans* Lesquereux. "Post-Laramie" (type), Black Buttes, Wyo.

Phylum PTERIDOPHYTA.

Class FILICES.

Order FILICALES.

Family POLYPODIACEAE.

Acrostichum hesperium Newberry.

Acrostichum hesperium Newberry, U. S. Nat. Mus. Proc., vol. 5, p. 503, 1882 [1883]; U. S. Geol. Survey Mon. 35, p. 6, pl. 61, figs. 2-5, 1898.

The illustrated types of this splendid fern are all preserved in the United States National Museum (Nos. 7013-7016).

Occurrence: Green River formation, Green River, Wyo., collected by C. A. White.

Family SCHIZAEACEAE.

Lygodium kaulfussii Heer.

Plate XXXVI, figure 7.

Lygodium kaulfussii Heer, Beiträge zur nähern Kenntniss der sächsisch-thuringischen Braunkohlenflora, p. 400, pl. 8, fig. 21; pl. 9, fig. 1, 1861.

Newberry, U. S. Geol. Survey Mon. 35, p. 1, pl. 62, figs. 1-4, 1898.

Knowlton, U. S. Geol. Survey Mon. 32, pl. 2, p. 672, pl. 80, figs. 1, 2, 1898.

Lygodium neuropteroides Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1870, p. 384, 1871; U. S. Geol. Survey Terr. Rept., vol. 7 (Tertiary flora), p. 61, pl. 5, figs. 4-7; pl. 6, fig. 1, 1878.

The genus *Lygodium* is so characteristic in shape and nervation that with reasonably adequate material it is easily and certainly identified. Its presence in the Green River formation was first made known by Lesquereux, who described and figured *Lygodium neuropteroides*. Subsequently a very large number of very well preserved examples were procured from the Green River formation by J. S. Newberry. These were identified as Lesquereux's species, and, as Newberry said, "They illustrate the growth of the plant far better than those he figured. Coming all from the same locality, indeed thickly impacted together and having the same nervation, they unquestionably represent a single species."

Before Newberry's account was published, however, Gardner[38] published an account of British Eocene ferns in which he pointed out the identity of Lesquereux's *Lygodium neuropteroides* with Heer's *Lygodium kaulfussii*, and this view was accepted by both Lesquereux and Newberry. Lesquereux was shown specimens of the true *Lygodium kaulfussii* and pronounced them "positively identical" with his species from the Green River formation. If there is any difference it is that the American specimens are somewhat more robust and have slightly broader and less undulate lobes, but the differences are not great.

Newberry[39] also reported *Lygodium* leaves from Fletts Creek and Carbonado, Wash. [Puget group], which, he said,

> offer no characters by which they can be distinguished from those found in the Green River group, and it seems to me probable that we have in all these specimens relics of one of those widespread and long-lived species which occur at different geological horizons among both animal and plant remains.

Newberry's conclusion has since been verified by the finding of specimens identified[40] as *Lygodium kaulfussii* on Elk Creek, in the Yellowstone National Park, in beds believed to be of Fort Union age, and also on the bank

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[38] Gardner, J. S., British Eocene flora, pt. 1, Filices, p. 47, pls. 7, 1884.

[39] Newberry, J. S., U. S. Geol. Survey Mon. 35, p. 3, 1898.

[40] Knowlton, F. H., U. S. Geol. Survey Mon. 32, pt. 2, p. 672, pl. 80, figs. 1-3, 1898.

Liquidambar gracile Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1871, p. 287, 1872.

From Bridger Pass, Wyo., hence excluded. (See p. 138.)

Arundo göpperti Münster. Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1871, Suppl., p. 5, 1872; U. S. Geol. Survey Terr. Rept., vol. 7 (Tertiary flora), p. 86, pl. 8, figs. 3–5.

This species is rejected from the Green River flora and probably should not be recognized in North America. In the "Tertiary flora" Lesquereux figured three specimens that he referred to this species. Of these only one, the original of his Plate VIII, figure 3, is now preserved in the United States National Museum (No. 95), and is before me. It is fully 8 centimeters wide, nearly three times the size of the largest specimen figured by Heer,[30] and is very unlike Heer's figure in appearance. It is marked with numerous fine longitudinal veins or lines, and at fairly regular intervals, about 1 centimeter apart, are stronger lines or folds. It may be a large leaf of *Cyperacites* or possibly a palm leaf. It is too indefinite to be identified.

Blechnum göpperti Ettingshausen. Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1871, p. 283, 1872.

From Henry's Fork, Utah: not again referred to by Lesquereux.

Carya heerii (Ettingshausen) Heer. Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1871, p. 289, 1872.

Not afterward recognized by Lesquereux.

Cinnamomum scheuchzeri Heer. Lesquereux, U. S. Geol and Geog. Survey Terr. Ann. Rept. for 1871, Suppl., p. 7, 1872.

Concerning this species Lesquereux said: "I refer to this species two leaves of *Cinnamomum*, one of which is contracted above the base, as in some forms of *C. buchi* Heer; the other narrower, like a variety of *C. lanceolata* Heer. Both specimens are incomplete and have the nervation of *C. scheuchzeri*, as represented in many specimens from other localities of our Tertiary." This species was not again alluded to as a member of the Green River flora, and the two leaves were probably transferred to some other species, but of this there is no record; they are not now known to be in existence.

Cyperites deucalionis Heer. Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1871, p. 285, 1872.

From Barrel Springs, Wyo.; not afterward referred to by Lesquereux.

Cyperus braunianus? Heer. Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1871, p. 285, 1872.

From Barrel Springs, Wyo.; not afterward mentioned by Lesquereux.

Cyperus chavanensis Heer. Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1871, p. 300, 1872.

Not from the Green River formation. (See p. 137.)

Equisetum haydenii Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1871, p. 284, 1872; U. S. Geol. Survey Terr. Rept., vol: 7 (Tertiary flora). pl. 6, figs. 2–4. 1878.

Ficus arenacea Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1871, p. 300, 1872.

Not from the Green River formation. (See p. 137.)

Ficus gaudini Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1871, p. 200, 1872.

Not from the Green River formation. (See p. 137.)

Ficus lanceolata Heer. Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1871, p. 300, 1872.

Not from the Green River formation. (See p. 137.)

Ficus multinervis Heer. Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1871, p. 300, 1872.

Not from the Green River formation. (See p. 137.)

Ficus populina Heer, Flora tertiaria Helvetiae, vol. 2, p. 66, pl. 85, figs. 1–7; pl. 86, figs. 1–11, 1856; Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1871, Suppl., p. 6, 1872.

Ficus populina was characterized by Heer from specimens obtained in the Swiss Miocene. A number of leaves from the Green River formation were identified by Lesquereux with Heer's species, although he states that they show "some marked differences," such as being obtuse rather than long and acutely pointed, having the veins nearer the borders, and having the marginal teeth pointed rather than round. There is a great deal of variation in the size and appearance of the forms referred to *Ficus populina* by Heer, and as Lesquereux did not specify the particular forms he regarded as most like those he had from Green River there is no way of telling where he later referred them. This species will have to be excluded from the Green River flora.

Geonomites goldianus (Lesquereux) Lesquereux, U. S. Geol. Survey Terr. Rept., vol. 7 (Tertiary flora), p. 115, pl. 9, fig. 9, 1878.

Wrong identification.

Palmacites goldianus Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1874, p. 311, 1875.

From Barrel Springs, Wyo.

Hemitelites torrelli Heer? Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1871, Suppl., p. 5, 1872.

Not afterward referred to by Lesquereux.

Ilex dissimilis Lesquereux, U. S. Geol. Survey Terr. Rept., vol. 7 (Tertiary flora), p. 271, pl. 50, figs. 7–9, 1878.

This species comes from Sage Creek, Mont., in beds of doubtful age. There seems no longer any valid reason for including this in the Green River formation, even with a question, and it is excluded.

Ilex stenophylla Unger. Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1871, Suppl., p. 8, 1872.

Not afterward mentioned by Lesquereux in connection with the Green River flora.

Juglans acuminata Heer? Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1871, Suppl., p. 8, 1872.

Lesquereux compares his Green River leaf with a peculiar form of *Juglans acuminata* from the Swiss Miocene, but as he did not afterward allude to it in this connection it was probably placed under some other form without record of such transfer.

Juglans dentata Newberry, U. S. Nat. Mus. Proc., vol. 5, p. 507, 1882 [1883].

Although this species was described by Newberry it was evidently merged with some other species in the

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[30] Heer, Oswald, Flora tertiaria Helvetiae, vol. 1, pl. 23, fig. 1, 1854.

are dimorphous, with simply pinnate fronds (simple in one species) with linear segments bearing parallel linear synangia, each composed of two rows of closely packed sporangia opening by a terminal pore. These fruiting characters are so strongly marked that there is little difficulty in recognizing a fossil form that is adequately preserved.

The species here described is not only the first North American fossil form to be made known, but it is apparently the only fossil species thus far described from any part of the world that is reasonably authenticated. Thus, Racyborski[41] described a species from the Jurassic of Krakow, Poland, under the name *Danaea microphylla*, but it has the outline, size, and nervation of a *Taeniopteris* (cf. *T. parvula* Heer). The fruit as figured may entitle it to be included in the Marattiaceae, but it is so unlike the fruit of *Danaea* that it can hardly be placed in this genus. Several Carboniferous species were described originally under the name *Danaea*, but they have later and more correctly been referred to *Danaeites*, *Danaeopsis*, etc.

The Marattiaceae are supposed to be of very ancient lineage—in fact, up to a decade or so ago it was commonly believed that they formed a dominant element in the forests of the coal age, but with the discovery of the "ever-widening territory of the pteridosperms" they have been brought more or less in question. Arber says:

> The evidence, formerly regarded as beyond suspicion. that the eusporangiate ferns formed a dominant feature of the vegetation of the Paleozoic period has been undermined, more especially by the remarkable discovery of the male organs of *Lyginodendron* by Mr. Kidston. At best we can only now regard them as a subsidiary group in the epoch of the past history of the vegetable kingdom.

Even the reproductive organs are no longer decisive unless the seeds are found, for, as Seward says:

> We can not in most cases be certain whether the small sporangium-like bodies on fertile pinnules are true fern sporangia or the micro-sporangia of a heterosporous pteridosperm. What is usually called exannulate fern sporangium * * * has no distinguishing features which can be used as a decisive test. The microsporophylls of the Mesozoic Bennettitales produced their spores in sporangical compartments grouped in synangia like those of recent Marattiaceae.

The Pteridospermae so far as known disappeared with the end of the Paleozoic era, and the marattiaceous type was carried on to the present by sparsely represented forms, such as *Marratiopsis*, *Danaeopsis*, *Bernouillia*, and perhaps *Nathorstia* of the Lower Cretaceous of Greenland, and a supposed Tertiary species of *Marattia* (*M. hookeri* Gardner and Ettinghausen) from the Eocene of the Isle of Wight. It is therefore of interest to be able to add another step in the recorded progress from the Paleozoic to the present in the shape of an undoubted *Danaea* from the middle Eocene of America.

This specimen has been submitted to Mr. Wm. R. Maxon, of the United States National Herbarium, and he pronounces it unqualifiedly as referable to *Danaea*.

Occurrence: Green River formation, oil shale, Rio Blanco County, about 40 miles southwest of Meeker, Colo., collected by D. E. Winchester, 1917.

Order EQUISETALES.

Family EQUISETACEAE.

Equisetum wyomingense Lesquereux.

Equisetum wyomingense Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1873, p. 409, 1874; U. S. Geol. Survey Terr. Rept., vol. 7 (Tertiary flora), p. 69, pl. 6, figs. 8–11, 1878.

Newberry. U. S. Geol. Survey Mon. 35, p. 15, pl. 65, fig. 8, 1898.

Lesquereux's description and figures of this species are rather vague and unsatisfactory. He states that the specimens are preserved on a large slab of very hard white shale, which is "covered with a profusion of fragments of the same plants, rootlets, rhizomes, stems crushed, pressed together, and rarely separated distinctly enough to clearly show their characters." He further states that the stems and rhizomes are equally and regularly striate, and the "sheaths are dentate on the borders, and short." The stems and rhizomes are of equal size, about half a centimeter in width.

Newberry figures a single stem from Green River under Lesquereux's name but makes no comment or comparison in the text. The figured specimen is a fragment of stem about 6 centimeters long and 0.5 centimeter wide and shows three sheaths with some 10 or 12 slender, sharp-pointed teeth. It is difficult to determine whether this is really the same as Lesquereux's *Equisetum wyomingense*, but it perhaps is best left as at present pending additional information.

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[a] Racyborski, Maryjan, Pamietnik Akad. Umiejetn., vol. 18, p. 155, pl. 6, figs. 1–6, 1894.

Occurrence: Green River formation, type found 3 miles east of Green River, Wyo.; Newberry's specimen from Green River.

Phylum SPERMATOPHYTA.

Class ANGIOSPERMAE.

Subclass MONOCOTYLEDONES.

Order GRAMINALES.

Arundo reperta Lesquereux.

Arundo reperta Lesquereux, U. S. Geol. and Geog. Survey Terr. Bull., vol. 1, p. 384, 1875 [1876]; idem, Ann. Rept. for 1874, p. 311, 1876; U. S. Geol. Survey Terr. Rept., vol. 7 (Tertiary flora), p. 87, pl. 8, figs. 6–8, 1878.

This species, it seems to me, is very unsatisfactory, and the propriety of recognizing it is doubtful. It was described by Lesquereux as follows:

> Stem thick, distinctly articulate; surface striate, marked with round obtuse knots, either placed at the articulation or here and there scattered upon the stem; fruiting panicle crushed, oval-oblong, bearing ovate-lanceolate seeds, and pallets mixed with a coating of hairs.

All the figured types of this form are in the United States National Museum (Nos. 96, 119) and are before me. The stem is striate, as described, and was apparently circular in cross section before it was entombed but is now much flattened. It may have been a hollow reedlike stem, but it also suggests a decorticated branch of a tree. The so-called articulation is only a check or crack filled with mud and thus simulating a joint. The "knots" are difficult to interpret. There are two in line with the axis of the stem, and they are about 7 millimeters in diameter and some 3 millimeters high. They seem to rest on and hardly to be a part of the organic structure of the stem—in fact, they have much the appearance of being little mud balls that happened to lodge on the specimen.

The specimen described as an underground stem is apparently correctly placed—that is to say, the scars, which occur at fairly regular intervals, are clearly the scars of roots or rootlets. The type specimen is fully 18 centimeters long and shows little diminution in size.

The cluster of seeds, although seemingly quite complete as depicted in the drawing, are really so obscure and fragmentary as to be almost impossible of accurate determination. A few of the specimens have somewhat the appearance of the palets of a large grass, but I should hesitate to say positively that this is their nature.

There is also little basis for supposing that these several organs are really parts of one species of plant. They are, indeed, associated on the same piece of matrix, but there is no positive evidence of former organic union.

With the above strictures this form is left as last revised by Lesquereux, but with the frank admission that it is seemingly of very little biologic or stratigraphic value.

Occurrence: Green River formation, Green River, Wyo., above the fish beds.

Family CYPERACEAE.

Cyperus chavannesi Heer.

Cyperus chavannesi Herr, Flora tertiaria Helvetiae, vol. 1, p. 72, pl. 22, fig. 7; pl. 28, fig. 1, 1855.

Cyperus "chavanensis"? Heer. Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1871, p. 291, 1872; U. S. Geol. Survey Terr. Rept., vol. 7 (Tertiary flora), p. 92, pl. 9, figs. 1, 2, 1878.

Lesquereux first mentioned this species as coming from Evanston, Wyo., "below the coal." Later, in the "Tertiary flora," it was given as coming from Green River, Wyo., and one of the figured specimens (pl. 9, fig. 1, U. S. Nat. Mus. No. 122) is in the United States National Museum. It is a mere fragment from the middle area of a large leaf and must be considered as doubtfully the same as the European type.

Occurrence: Green River formation, Green River, Wyo.

Cyperacites haydenii (Lesquereux) Knowlton.

Cyperacites haydenii (Lesquereux) Knowlton, U. S. Geol. Survey Bull. 152, p. 83, 1898.

Cyperites haydenii Lesquereux, U. S. Geol. Survey Terr. Rept., vol. 8 (Cretaceous and Tertiary floras), p. 140, pl. 23, figs. 1–3a, 1883.

The types of this species are preserved in the United States National Museum (Nos. 1565, 1569). It has been well described and figured by Lesquereux.

Occurrence: Green River formation, Uinta (formerly incorrectly given as Randolph) County, Wyo.

Order ARECALES.

Family ARECACEAE.

Geonomites haydenii (Newberry) Knowlton, n. comb.

Manicaria haydenii Newberry, U. S. Nat. Mus. Proc., vol. 5, p. 504, 1883; U. S. Geol. Survey Mon. 35, p. 31, pl. 64, fig. 3, 1898.

The following description was given by Newberry:

> Frond large, leaves pinnately plicated, folds 1.5 centimeters in width above, slightly narrowed below; flat or gently arched, smooth, springing from the midrib at an angle of 25°, 30° below; folds attached to the midrib [rachis] obliquely by the entire width, and to each other by their entire length (?); nervation fine, uniform (?), parallel.

This Green River palm is very imperfectly known—in fact, the only specimen I have seen is the type as figured by Newberry (U. S. Nat. Mus. No. 7016). It is impossible to determine the position of this fragment in relation to the whole leaf, though from its size as compared with leaves from other localities believed to be congeneric with it, it was probably from the middle or lower portion.

Newberry was frank to state in the discussion of his *Manicaria haydenii* that it certainly belongs to the same genus as Lesquereux's *Geonomites tenuirachis*,[42] and with this statement I am inclined to agree. I have figured[43] a much larger and far more nearly complete specimen of *Geonomites tenuirachis*, from the Raton formation, than Lesquereux's type, and from this it is fairly clear that the type specimen is a small segment from the upper portion of the leaf. I can see no characters by which this Green River palm can be excluded from *Geonomites*, and consequently I have transferred it to this genus. It seems closer to *Geonomites tenuirachis* than to *Manicaria formosa* Heer,[44] from the Swiss Miocene, with which Newberry compared it—in fact, it would be difficult with the scant material available to separate them specifically. However, as they are so imperfectly known, and as there is so much difference in their stratigraphic position, it is perhaps best to regard *Geonomites haydenii* as distinct until its status can be settled with better material.

Occurrence: Green River formation, Green River, Wyo.

Sabal powellii Newberry.

Sabal powellii Newberry, U. S. Nat. Mus. Proc., vol. 5, p. 504, 1882 [1883]; U. S. Geol. Survey Mon. 35, p. 30, pl. 63, fig. 6; pl. 64, figs. 1, 1a, 1898.

The following is Newberry's description:

> Leaves of medium size, 4 or 5 feet in diameter, petiole smooth, unarmed, terminating above in an angular or rounded area from which the folds diverge beneath, concavely narrowing to form a spike 3 or 4 inches in length; rays about 50, radiating from the end of the petiole, perhaps 60 in the entire leaf, compressed to acute wedges where they issue from the petiole; strongly angled and attaining a maximum width of about 1 inch; nerves fine, about 12 stronger ones on each side of the keel, with finer intermediate ones too obscure for enumeration.

Although the remains of palms are abundant in a number of Tertiary formations they are unusually difficult of satisfactory diagnosis. Their large size, the fragmentary state in which they are usually collected, and the lack of good diagnostic characters in the leaves make their identification more or less uncertain. The allocation of *Sabal powellii* is a case in point. In his discussion Newberry points out that it bears considerable resemblance to *Sabal? eocenica* (Lesquereux) Knowlton (formerly *Flabellaria eocenica*) as figured by Lesquereux,[45] differing in having a larger number of folds and a longer point of support on the under side of the leaf. Newberry also compares his species to *Sabalites grayanus* (Lesquereux) Lesquereux, but this has been since divided. The type locality was the Wilcox group of the Gulf region, and the name *Sabalites grayanus* is retained for this form, which has also been reported from the Laramie, Lance, and Raton formations. The large leaves, which are evidently the ones Newberry had in mind, mainly from the Montana group, have been separated under the name *Sabal? montana* Knowlton.[46] Although this species is still imperfectly known it seems to be distinguishable by its very large size, being perhaps the largest palm in the Rocky Mountain region, and by the greater number of folds (about 90).

Sabal grandifolia Newberry[47] is another large-leaved palm that may be compared with *Sabal powellii*. It has nearly twice the number of folds.

Occurrence: Green River formation, Green River, Wyo.

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[42] Lesquereux, Leo, U. S. Geol. Survey Terr. Rept., vol. 7 (Tertiary flora), p. 117, pl. 11, fig. 1, 1878.

[43] Knowlton, F. H., U. S. Geol. Survey Prof. Paper 101, p. 291, pl. 62, 1917.

[44] Heer, Oswald, Flora tertiaria Helvetiae, vol. 1, pl. 38, 1856.

[45] Lesquereux, Leo, U. S. Geol. Survey Terr. Rept., vol. 7 (Tertiary flora), pl. 13, figs. 1-3, 1878.

[46] Knowlton, F. H., U. S. Geol. Survey Prof. Paper 101, p. 253, pl. 32, fig. 3, 1918.

[47] Newberry, J. S., U. S. Geol. Survey Mon. 35, p. 28, pl. 25; pl. 63, fig. 5 (not pl. 64, figs. 2, 2a), 1898.

Flabellaria florissanti Lesquereux.

Flabellaria florissanti Lesquereux, U. S. Geol. Survey Terr. Rept., vol. 8 (Cretaceous and Tertiary floras), p. 144, pl. 24, figs. 1-2a, 1883.

The following is Lesquereux's characterization of this species:

> Fronds large; rays diverging all around from the top of the long, nearly flat, unkeeled rachis; rays large, very numerous, acutely keeled; primary nerves distinct; close intermediate veinlets three or four.

Lesquereux did not give any actual dimensions, and the two figured types are all of the original material now known to be extant. Subsequently, however, L. F. Ward collected extensively at Green River station, at a point known locally as Bell's fish cliff, and procured some very large palm leaves that in all reasonable probability are the same as Lesquereux's species. It must have been at least 5 feet in diameter and has the same rather slender petiole as the figured type. Our specimen includes the outer edge of the leaf and shows that the rays are split apart for a distance of at least 20 centimeters.

Occurence: Green River formation [types], Uinta (formerly incorrectly called Randolph) County, Wyo.; Bell's fish cliff, Green River, Wyo., collected by L. F. Ward.

Order XYRIDALES.

Family PONTEDERIACEAE.

Genus PONTEDERITES Knowlton, n. gen.

Pontederites hesperia Knowlton, n. sp.

Plate XXXVI, figure 6.

Although it is perhaps more or less hazardous to base a new genus on a single fragment, the present one seems so distinct that it merits at least temporary characterization until more complete material can be procured. It is the well-preserved upper part of a leaf that was presumably broadly ovate below and rather abruptly narrowed above into a deltoid-lanceolate apical portion, 1 centimeter wide at the base, 2 centimeters long, and acute at the tip. The length of the part preserved is 8 centimeters and the width about 5 centimeters. The total length was presumably not less than 12 or 15 centimeters. It is unfortunate that the shape of the base is unknown. The nervation consists of numerous close, mainly parallel veins that arise from a slightly enlarged midvein which is reduced in the apical portion to the same size as the other veins. Those that can be seen arise from the midvein at a very acute angle—about 80°—but in the lower portion they are closer together and apparently arise at a less acute angle. The veins spread in the broad portion of the blade, then approach again in the upper part, where some of them terminate, only about a dozen passing into the reduced apical portion. A few intermediate veins come up from the lower portion of the blade and die out above, but so far as can be ascertained there are no fine intermediate veinlets, or at least but faint traces of them. There are, however, numerous cross veinlets, mainly at right angles to the veins.

This leaf appears to resemble most closely the leaves of *Pontederia cordata* Linné, the well-known pickerel weed, which grows on the borders of ponds and streams from Nova Scotia to Minnesota and south to Florida and Texas. In the living plant the thick, petioled leaves are ovate, cordate-sagittate, and 5 to 20 centimeters long, with the basal and apical lobes rounded. It has a fairly distinct midrib in the lower portion, but this disappears above. It is, of course, much to be regretted that the basal portions of these leaves can not be compared, but such a comparison must await more nearly perfect specimens. So far as the available material goes I can see no essential difference between the fossil and the living forms, and the name given to the genus brings out this point.

The fossil has some resemblance to certain forms that have been referred to *Canna*, such as *Canna eocenica* Berry,[48] from the Wilcox group of the Gulf region, but this is more nearly lanceolate, with no contraction into the reduced apical portion. The midrib is also stronger in *Canna eocenica*.

The only other Green River monocotyledon with which it could possibly be compared is *Musophyllum complicatum* Lesquereux,[49] but this is of a totally different character.

Under the name *Zingiberites dubius* Lesquereux[50] described a fragment from the Denver formation of Colorado, but this is too much broken to give any reliable conception of its form and size, and hence it can not be compared with the present form.

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[48] Berry, E. W., U. S. Geol. Survey Prof. Paper 91, p. 181, pl. 15, figs. 7, 8, 1916.

[49] Lesquereux, Leo, U. S. Geol. Survey Terr. Rept., vol. 7 (Tertiary flora), p. 96, pl. 15, figs. 1-6, 1878.

[50] Idem, pl. 16, fig. 1.

Occurrence: Green River formation, Greasewood Creek, Rio Blanco County, 40 miles west of Meeker, Colo., collected by D. E. Winchester, 1917.

Order LILIALES.

Family JUNCACEAE.

Juncus sp. Lesquereux.

Juncus sp. Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1871, Suppl., p. 6, 1872.

Lesquereux says:

> Fragments of stems of various sizes, like *Juncus retractus* Heer, or *Juncus scheuzeri* Heer, in Flora tertiaria Helvetiae, pl. 30, figs. 2c, 3c.

These specimens are not known to be in existence, and the species should probably be discarded.

Occurrence: Green River formation, Green River, Wyo.

MONOCOTYLEDONAE OF UNCERTAIN POSITION.

Musophyllum complicatum Lesquereux.

Musophyllum complicatum Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1873, p. 418, 1874; U. S. Geol. Survey Terr. Rept., vol. 7 (Tertiary flora), p. 96, pl. 15, figs. 1–6, 1878.

Most of the type material on which this species is based is preserved in the United States National Museum (Nos. 132–135). It is very obscure and difficult to interpret, and on this point Lesquereux said:

> The exact character of these leaves, especially their form, their size, and their relation to the main stem, or stipe, is very obscure. I have found a bed of shale nearly 1 foot thick filled entirely with fragments of this species and have worked a whole day with a miner, trying, without avail, to get specimens more definite than those which are figured here. Large pieces of shale are covered with fragments of leaves, folded in various ways, where no trace of any middle nerve may be discovered. This proves the large size of the leaves.

As nearly as can be made out it may be described as follows: Stem or stipe very stout, at least 3 centimeters in width, longitudinally wrinkled and striate. Leaves large, with a thick irregularly veined midrib 1 centimeter or more in width. Veins of the leaf numerous, thin but distinct, mainly simple but occasionally dichotomous, especially toward the margins.

Occurrence: Green River formation, 8 miles southeast of Green River station, Wyo.

Subclass DICOTYLEDONES.

Order SALICALES.

Family SALICACEAE.

Salix linearis Knowlton, n. sp.

Plate XXXVII, figure 8.

Leaf very small, linear-lanceolate, 3.5 centimeters long, 5 millimeters broad, with a petiole 5 millimeters long; margin with a few rather remote teeth; midrib very strong; secondaries as many as the teeth, which they enter, arising at an angle about 40°, little curved upward; finer nervation not discernible.

This little leaf is also the only one of its kind observed in the collections. It is perhaps hazardous to characterize a new *Salix* on a single leaf, but it differs so clearly from any other in the collection that it is presented with the reservation that it may be shown to belong elsewhere when more material is available.

Among living species this strongly resembles a small leaf of *Salix fluviatilis* Nuttall, the well-known sand-bar or river-bank willow, which ranges from Quebec to Oregon and south to Virginia, Kentucky, and New Mexico. There is no fossil species, at least from the Green River, that could be confused with this.

Occurrence: Green River formation, Rio Blanco County, 20 miles west of Rio Blanco post office, Colo. (sec. 33, T. 4 S., R. 100 W.), collected by D. E. Winchester, 1917.

Salix longiacuminata Knowlton, n. sp.

Leaves thin but firm in texture, lanceolate, broadest a short distance above the base, whence it is gradually narrowed to a long, slenderly acuminate apex and to a wedge-shaped base; margin slightly irregular though scarcely to be called toothed; length 9 or 10 centimeters, width 1.2 centimeters; petiole slender, about 1.75 centimeters long; midrib relatively very strong, especially in the lower third; secondaries numerous, arising at various angles, in the lower part falling below a right angle, then many nearly at a right angle, and finally some at an angle of perhaps 20°; all secondaries curved and each joining the one next above, forming a series of loops just within the margin; intermediate secondaries numerous; finer nervation irregularly quadrangular.

The only specimen found in the collections, a nearly perfect leaf, seems well characterized by its long, slenderly acuminate apex, thick midrib, and very numerous secondaries, which arise at various angles and by joining form a series of bows well inside the margin.

This leaf is not greatly different in size and shape from leaves referred by Lesquereux [51] to *Salix angusta*, though it is more slenderly acuminate, but it differs wholly in the secondary nervation. Thus, in *Salix angusta* the secondaries are numerous, close, parallel, and little curved upward, whereas in the present species the secondaries are more remote and by joining form a series of loops.

Among other fossil species the present one resembles in nervation *Salix arcinerva* Heer,[52] from the Swiss Miocene, but that species differs in shape and has the margin finely toothed. It also resembles in shape and somewhat in nervation *Salix longa* Heer,[53] from the same area, but that species is much larger and its secondaries do not form loops.

Occurrence: Green River formation, Rio Blanco County, 20 miles west of Rio Blanco post office, Colo. (sec. 33, T. 4 S., R. 100 W.), collected by D. E. Winchester, 1917.

Salix sp.

Plate XXXVII, figures 3–5.

The collection made by Winchester includes a number of small leaves that appear to belong to *Salix*, though the nervation is so obscure that this assignment is not certain. They are linear-lanceolate leaves, 3.5 to about 6 centimeters long and 6 to 10 millimeters wide, and have a petiole 5 or 6 millimeters long. They are narrowed to a wedge-shaped base and are rather obtuse at the apex. The margin is perfectly entire. The nervation, with the exception of a relatively very strong midrib, is obscure but appears to consist of numerous thin secondaries at an angle of 35° or 40° that are camptodrome and arch just inside the margins; none of the finer nervation is observable.

Considering the uncertainty regarding these leaves it seems hardly worth while to attempt comparisons with either living or fossil species. Small, narrow, entire willow leaves are so nondescript that it is difficult to be sure of their subsequent recognition, and for this reason the present form has not been given a specific designation.

Occurrence: Green River formation, Rio Blanco County, about 40 miles southwest of Meeker, Colo., collected by D. E. Winchester, 1917.

Salix sp.

Salix media Heer. Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1871, Suppl., p. 6, 1872; U. S. Geol. Survey Terr. Rept., vol. 7 (Tertiary flora), p. 168, pl. 22, fig. 3, 1878.

The specimen on which Lesquereux based the presence of *Salix media* Heer in American beds is in the United States National Museum (No. 198). It is a small leaf about 7 centimeters long and lacks most of one side and the tip. It is without a trace of nervation except a strong midrib, though secondaries have been added in the figure given in the "Tertiary flora." The leaves from the Swiss Miocene referred by Heer [54] to *Salix media* are all mostly without nervation except the midrib, and of course it is easy to match the American leaf with one of these, but such a comparison is obviously without value.

In the Museum collection there is another leaf not figured that was identified by Lesquereux as *Salix media*—in fact, it is recorded under the same number (198) as the other—but it is a long, narrow leaf with obscurely preserved nervation in which a small portion is so preserved as to show an intramarginal vein, as in *Eucalyptus? americana*, and it should be referred to that species.

As the leaf figured by Lesquereux is so obscure it is here removed from *Salix media* and regarded as *Salix* sp.

Occurrence: Green River formation, Green River, Wyo.; also reported from Elko, Nev.

Order MYRICALES.

Family MYRICACEAE.

Myrica salicina Unger.

Myrica salicina Unger, Genera et species plantarum fossilium, p. 396, 1850.

Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1871, Suppl., p. 6, 1872.

The status of this species is doubtful. It was identified by Lesquereux under the above name, but the specimen on which the identification was based is lost or merged with something else without a record of such transfer. It was neither figured nor again referred to by Lesquereux.

Occurrence: Green River formation, Green River, Wyo.

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[51] Lesquereux, Leo, U. S. Geol. Survey Terr. Rept., vol. 7 (Tertiary flora), pl. 22, fig. 4, 1878.

[52] Heer, Oswald, Flora tertiaria Helvetiae, vol. 2, pl. 65, figs. 4, 5, 1856.

[53] Idem, pl. 69, figs. 12, 13.

[54] Heer, Oswald, Flora tertiaria Helvetiae, vol. 2, pl. 68, figs. 14–19, 1856.

Myrica minuta Knowlton, n. sp.

Plate XXXVII, figure 12.

Leaves coriaceous or at least firm in texture, linear-lanceolate, prolonged above to a slender acuminate apex and scarcely less so below to the narrowly wedge-shaped base; margin entire for the lower third, thence rather strongly toothed, the teeth moderately sharp; midrib relatively strong; secondaries numerous, thin, at an angle of about 40°, slightly curved upward, ending in the margin in the lower untoothed portion and in the teeth in the middle and upper portion.

This little leaf, the only one observed, is about 18 millimeters long and 3 millimeters wide and has a delicate petiole 1 millimeter long. It is evidently rather thick, as the secondary nervation is faintly visible.

This species is of the same type as *Myrica scottii* Lesquereux, from the Florissant lake beds, but it is only one-fourth the length of that species and has rather blunt instead of very sharp teeth.

Occurrence: Green River formation, oil shale, Smith ranch, on Greasewood Creek, about 40 miles southwest of Meeker, Colo., collected by D. E. Winchester, 1917.

Myrica praedrymeja Knowlton, n. sp.

Plate XXXVI, figures 1-3.

Leaves small, firm in texture, lanceolate, acuminate at apex, rounded below, with the sides of the leaf at angles of about 45°, slightly unequal sided; margin entire for a short distance, thence with numerous rounded teeth; petiole short, stout; midrib relatively very strong, straight; secondaries numerous, 18 or 20 pairs, alternate, close, parallel, little curved upward, ending in the teeth; finer nervation obsolete.

This species is represented by a number of specimens, and three of the most nearly perfect ones are figured. They are 4 or 5.5 centimeters long and about 1.2 centimeters wide, with the petiole at least 4 millimeters long. This species is very closely similar to *Myrica callicomaefolia* Lesquereux[55] (now *Myrica drymeja* (Lesquereux) Knowlton), from the Florissant lake beds—in fact, they may be identical. *M. praedrymeja* differs slightly, however, in having the marginal teeth obtuse or rounded instead of sharp-pointed and a stronger nervation. These differences are not marked, and a fuller series might readily show them breaking down.

Occurrence: Green River formation, oil shale, Smith ranch, on Greasewood Creek about 40 miles southwest of Meeker, Rio Blanco County, Colo., collected by D. E. Winchester, 1917.

Myrica ludwigii Schimper.

Myrica ludwigii Schimper, Paléontologie végétale, vol. 2, p. 545, 1872.

Lesquereux, U. S. Geol. and Geog. Survey Terr. Bull., vol. 1, p. 385, 1875 (1876); idem, Ann. Rept. for 1874, p. 311, 1876; U. S. Geol. Survey Terr. Rept., vol. 7 (Tertiary flora), p. 133, pl. 65, fig. 9, 1878.

The single broken leaf figured is all there is to represent this species, and this is now lost. Its status is therefore rather unsatisfactory, but it will have to stand as above until further material can be procured.

Occurrence: Green River formation, mouth of White River (emptying into Green River), Wyo.

Myrica sp.

Plate XXXVII, figure 2.

Winchester's collection contains a fragment that evidently belongs to *Myrica*, but it is so deficient that I have not given it a specific name. It is a fragment 2.5 centimeters long and 0.5 centimeter wide, of the upper part of a linear-lanceolate, sharply acuminate leaf. The margin in the lower part is nearly entire, with only an occasional tooth, but in the upper part it is provided with low, obtuse, irregularly spaced teeth. The nervation consists of a relatively strong, straight midrib and very numerous secondaries that arise at a low angle and curve slightly in passing to the borders, which most of them seem to enter. These secondaries are somewhat irregularly placed; the finer nervation is not observable.

This form has the same type of nervation as *Myrica nigricans* Lesquereux, but it differs in the narrowly lanceolate, acuminate, irregularly toothed blade.

Occurrence: Green River formation, Cathedral Bluff, south of Little Tommies Draw, 20 miles west of Rio Blanco post office, Rio Blanco County, Colo., collected by D. E. Winchester, 1917.

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[55] Lesquereux, Leo, U. S. Geol. Survey Terr. Rept., vol. 8 (Cretaceous and Tertiary floras), p. 146, pl. 26, figs. 5-14, 1883.

Myrica sp.

Plate XL, figure 13.

In the Winchester collection I find the single specimen here figured, which seems to be different from any other noted. It is coriaceous in texture, narrowly lanceolate, prolonged above into an acute apex (base destroyed). It was probably 9 or possibly 10 centimeters long and about 13 millimeters wide. The margin is remotely toothed, the teeth low and rather obtuse. The nervation consists of a very strong, straight midrib and numerous pairs of mainly alternate secondaries which arise nearly at right angles to the midrib, considerably curved upward and ending in the teeth or in the margin; finer nervation not well preserved.

This somewhat resembles what Lesquereux called *Myrica nigricans*[56] (now *Rhus nigricans*), but it is longer and more narrowly acuminate, and has fewer secondaries. It is even closer to *Myrica ludwigii* Schimper, as identified by Lesquereux[57] from the mouth of White River, Wyo., but that species is shorter and broader and has very large marginal teeth and different secondary nervation.

Occurrence: Green River formation, head of Carr Creek, Garfield County, Colo., 30 miles northwest of De Beque, collected by D. E. Winchester, 1917.

Comptonia? anomala Knowlton, n. sp.

Plate XXXVII, figure 1.

Leaf small, sessile, 2 centimeters long, 6 millimeters wide; coriaceous; lanceolate, obtuse and rounded at apex, strongly unequal-sided at base; margin strongly undulate-toothed, the teeth low and rounded; midrib very strong for the size of the leaf; secondaries thin, opposite or nearly so, at a low angle, very little curved upward, ending in the marginal undulations; intermediate secondaries occasional; finer nervation obsolete.

It is with grave doubt that this little leaf is referred to the genus *Comptonia*. In the undulate-toothed margin and in nervation it seems identical with this genus, but the strongly unequal-sided base suggests that it is a leaflet and not a distinct leaf. However, I have not thus far been able to place it satisfactorily in any genus with compound leaves, and temporarily it is referred to *Comptonia*. It is so strongly marked that it can easily be recognized in future and perhaps more correctly placed when opportunity offers.

Occurrence: Green River formation, Smith ranch, on Greasewood Creek, about 40 miles southwest of Meeker, Rio Blanco County, Colo., collected by D. E. Winchester, 1917.

Order JUGLANDALES.

Family JUGLANDACEAE.

Juglans occidentalis Newberry.

Juglans occidentalis Newberry, U. S. Nat. Mus. Proc., vol. 5, p. 507, 1882 [1883]; U. S. Geol. Survey Mon. 35, p. 34, pl. 65, fig. 1; pl. 66, figs. 2-4 [not pl. 66, fig. 1], 1898.

Juglans schimperi Lesquereux, U. S. Geol. Survey Terr. Rept., vol. 7 (Tertiary flora), pl. 56, figs. 7, 8, 10 [not figs. 5, 6, 9, which remain under *Juglans schimperi*], 1878.

Hollick, Louisiana Geol. Survey Special Rept. 5, p. 280, pl. 33, fig. 1; pl. 25, fig. 3 [not pl. 32, fig. 5?; pl. 33, fig. 2, which remain under *Juglans schimperi*], 1899.

Berry, U. S. Geol. Survey Prof. Paper 91, p. 182, pl. 18, figs. 3, 5 [not pl. 18, fig. 4, which remains under *Juglans schimperi*], 1916.

Knowlton, U. S. Geol. Survey Prof. Paper 101, pl. 64, fig. 1, 1918.

Leaves supposedly pinnate; leaflets somewhat variable in form and size, from about 8 to 18 centimeters in length, 3 to 6 centimeters wide, generally about 15 centimeters long and 4 centimeters wide, broad lanceolate, broadest near the middle, summit acute, base rounded, unsymmetrical; margin entire; midrib very strong, straight; secondaries numerous, about 20 pairs, rather slender, at a low angle of emergence, slightly curved upward, camptodrome, forming a series of bows or loops along the margin; finer nervation not well retained, but nervilles mainly oblique to the secondaries and unbroken.

Juglans occidentalis was named and described by Newberry in 1883 but was not figured until the publication of his "Later extinct floras" in 1898. He stated that there were a large number of specimens in the collection submitted to him, some of which "are found attached to the stems that bore them, but generally separated and more or less torn and broken. The tree was evidently a strong-growing and luxuriant one, for some of the leaves are not less than 8 inches in length."

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[56] Lesquereux, Leo, U. S. Geol. Survey Terr. Rept., vol. 7 (Tertiary flora), p. 132, pl. 17, figs. 9-12, 1878.

[57] Idem, pl. 65, fig. 9.

Newberry called attention to the fact that his specimens were from the same locality as that which furnished the leaves described by Lesquereux as *Juglans schimperi* but concluded that the two were not identical, because Lesquereux had described *Juglans schimperi* as long, narrow leaves, broadest near the base and with a camptodrome nervation, whereas Newberry stated that in *Juglans occidentalis* "a large part of the lateral nerves terminate in the margins, and the tertiary nervation is more open and irregular."

The figured types of both species are before me and disclose that Newberry was wrong in saying that a large part of the nerves terminate in the margins in his species; they are all camptodrome and form loops along the margin, exactly as described by Lesquereux for his *Juglans schimperi.* This character therefore fails, and the only way of distinguishing them is by the long, narrow, sharp-pointed leaflets with a rounded equal-sided base and slightly more acute-angled secondaries in *Juglans schimperi,* and the broader, less acuminate leaflets with unequal-sided base and very low-angled secondaries in *Juglans occidentalis.* But, as pointed out in the discussion of *Juglans schimperi* below, the possibility should be considered that the leaflets now allocated to *Juglans schimperi* may be terminal leaflets, and if so all would naturally have to be included under Lesquereux's species. It is also pointed out in the discussion of *Juglans schimperi* that the disposition mentioned makes necessary certain transfers of figures from one to the other. Thus, those of Lesquereux's types of *Juglans schimperi* will go to *Juglans occidentalis.* All but two of the leaflets identified by Hollick as *Juglans schimperi* from the Wilcox group will go to *Juglans occidentalis,* as indicated in the above synonymy. These figures as reproduced by Berry in his paper on the Wilcox flora will have the same disposition, and the leaflets from the Raton flora that I identified as *Juglans schimperi* will also find place under *Juglans occidentalis.*

Occurrence: Green River formation, Green River, Wyo. Wilcox group, Louisiana and Mississippi. Raton formation, northeastern New Mexico and southeastern Colorado.

Juglans schimperi Lesquereux.

Juglans schimperi Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1871, Suppl., p. 8, 1872; U. S. Geol. Survey Terr. Rept., vol. 7 (Tertiary flora), p. 287, pl. 56, figs, 5, 6, 9 [not figs. 7, 8, 10, which=*Juglans occidentalis* Newberry], 1878.

Hollick, Louisiana Geol. Survey Special Rept. 5, p. 280, pl. 32, fig. 5?; pl. 33, fig. 2 [not pl. 33, fig. 1; pl. 35, fig. 3, which=*Juglans occidentalis* Newberry], 1899.

Berry, U. S. Geol. Survey Prof. Paper 91, p. 182, pl. 18, fig. 4; pl. 19, fig. 4? [not pl. 18, figs. 3, 5, which=*Juglans occidentalis* Newberry], 1916.

Leaves firm in texture, pinnately compound, leaflets lanceolate, 8 to 14 centimeters long, 2 to 3.5 centimeters wide, broadest near the abruptly rounded and equal-sided base, tapering to a long, slender point above; margin entire, slightly undulate; petiolule very short; midrib very strong, straight; secondaries numerous, about 18 pairs, rather thin, emerging at angles of 40° to 50°, close, parallel, slightly curved in ascending to the middle of the area, but more and gradually curved on nearing the margin, which they closely follow in simple bows; secondaries connected by close, distinct nervilles, generally at right angles to them.

Juglans schimperi was named and described by Lesquereux in 1872 but was not figured until the publication of the "Tertiary flora" in 1878. Six specimens were figured as the types, and all are in the United States National Museum and are before me. Although several of the specimens are fragmentary, it has long seemed to me that they show differences that might amount to specific distinctness, but they have never before been very critically examined. Three specimens (Tertiary flora, pl. 56, figs. 5, 8, 9) are long, narrowly acuminate leaflets with an equal-sided base, whereas the others (figs. 7, 8, 10) are markedly unequal-sided at the base and have the secondaries at a much lower angle.

A few years later Newberry studied a large number of very well preserved leaves from the same locality (Green River, Wyo.) that had supplied Lesquereux's types of *Juglans schimperi.* These Newberry [58] described and figured under the name *Juglans occidentalis.* It needs but a glance to show that so far as the base of the leaflets is concerned *Juglans occidentalis* is absolutely identical with the three figures above mentioned (figs. 7, 8, 10) of Lesquereux's *Juglans schimperi*, and the question immediately arises as to the disposition that is to be made of the various forms. If all the specimens figured by Lesquereux as types of his *Juglans schimperi* are considered as conspecific, then Newberry's *Juglans occidentalis* must be referred to it. However, it seems best to regard *Juglans schimperi* as a composite species and to retain the narrow, sharp-pointed leaflets with an equal-sided base and allocate them to Lesquereux's name, referring the unequal-sided specimens to *Juglans occidentalis*. The possibility is not to be lost sight of, however, that the narrow leaflets may be really terminal leaflets and hence would be likely to have an equal-sided base, but thus far no specimens have been found that show the leaflets attached.

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[58] Newberry, J. S., U. S. Geol. Survey Mon. 35, p. 34, pl. 65, fig. 1; pl. 66, figs. 1-4c, 1898.

The proposed splitting up of *Juglans schimperi* makes some complications with certain subsequent identifications. Thus, Hollick[59] referred a number of leaflets from the Wilcox group of Louisiana to *Juglans schimperi* Lesquereux. Of the four examples figured only one (pl. 33, fig. 2) appears to belong to Lesquereux's species as now restricted.

Hollick's figures above mentioned were republished by Berry[60] in his paper on the Wilcox flora, but only figure 4 of Plate XVIII is to be retained under *Juglans schimperi*, the others going to Newberry's species.

In my report on the flora of the Raton formation[61] I identified a single leaflet as *Juglans schimperi* on the basis of its resemblance to leaflets so identified by Hollick. This now becomes *Juglans occidentalis*.

Occurrence: Green River formation, Green River, Wyo. Wilcox group, Louisiana and Mississippi. Beds of Wilcox age, western Kentucky. Denver formation, Golden, Colo. Clarno formation (upper part), Bridge Creek, Oreg.

Juglans crossii Knowlton.

Juglans crossii Knowlton, U. S. Geol. Survey Bull. 152, p. 122, 1898.

Juglans denticulata Heer. Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1871, p. 298, 1872; U. S. Geol. Survey Terr. Rept., vol. 7 (Tertiary flora), p. 289, pl. 58, fig. 1, 1878. [Homonym, Weber, 1852.]

The first locality from which this species was identified by Lesquereux appears to have been the Bozeman coal field of Montana, in beds presumed to belong to the Livingston formation, but the only specimen figured in the "Tertiary flora" was obtained at Green River, Wyo., above the so-called fish beds. This specimen is in the United States National Museum (No. 482) and has been fairly well described and figured. This species has also been reported from the Hanna formation of Carbon, Wyo.

Juglans alkalina Lesquereux.

Juglans alkalina Lesquereux, U. S. Geol. and Geog. Survey Terr. Bull., vol. 1, p. 382, 1875 [1876]; idem, Ann. Rept. for 1874, p. 308, 1876; U. S. Geol. Survey Terr. Rept., vol. 7 (Tertiary flora), p. 288, pl. 62, figs. 6–9, 1878.

Leaves pinnately compound; leaflets lanceolate, tapering upward to a long acumen, either narrowed or rounded to a short petiole; borders crenulate; lateral veins distant, mostly alternate, parallel, separated by short intermediate tertiary veins, curving in passing toward the borders at an open angle of divergence and ascending high along them in festoons; nervilles in right angle to the veins, branching in the middle, and forming by subdivisions irregularly quadrate or polygonal meshes.—Lesquereux.

Three of the four types of this species—figures 6, 7, and 8 of Plate LXII in the "Tertiary flora"—are preserved in the United States National Museum collections (Nos. 527–529).

Occurrence: Green River formation, Alkali stage station, 30 miles north of Green River, Wyo.

Juglans winchesteri Knowlton, n. sp.

Plate XXXVIII, figure 5.

Leaflet firm in texture, elliptical or ovate-elliptical, strongly unequal-sided, broadest near the middle, thence gradually narrowed to an apparently rather obtuse apex and downward to the rounded base; margin entire below, then obscurely toothed, the teeth low; petiole short, very thick and stout, curved; midrib very thick just above the petiole, very much thinner above; secondaries ten or twelve pairs, alternate, at irregular distances, arising at very low angles, much curved upward, camptodrome, sending slender branches to the marginal teeth; nervilles strong.

The specimen figured is the only one of this species noted. It is about 9 centimeters long and 4.5 centimeters wide. The petiole is 3 millimeters thick and about 8 millimeters long.

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[59] Hollick, Arthur, Louisiana Geol. Survey Special Rept. 5, p. 280, pl. 32, fig. 5; pl. 33, figs. 1, 2; pl. 35, fig. 3, 1899.

[60] Berry, E. W., U. S. Geol. Survey Prof. Paper 91, p. 182, pl. 18, figs. 3–5; pl. 19, fig. 4, 1916.

[61] Knowlton, F. H., U. S. Geol. Survey Prof. Paper 101, p. 296, pl. 64, fig. 1, 1918.

Occurrence: Green River formation, Rio Blanco County, 20 miles west of Rio Blanco post office, Colo. (sec. 33, T. 4 S., R. 100 W.), collected by D. E. Winchester, 1917.

Order FAGALES.

Family FAGACEAE.

Quercus castaneopsis Lesquereux.

Quercus castaneopsis Lesquereux, U. S. Geol. Survey Terr. Rept. vol. 8 (Cretaceous and Tertiary floras), p. 155, pl. 28, fig. 10, 1883.

Quercus castanoides Newberry, U. S. Nat. Mus. Proc., vol. 5, p. 506, 1883; U. S. Geol. Survey Mon. 35, p. 70, pl. 65, fig. 6, 1898.

Leaf firm in texture, lanceolate or narrowly ovate-lanceolate, 12 to 16 centimeters long, 2.5 to 6 centimeters wide, narrowly acuminate at the apex, rather abruptly rounded to a wedge-shaped base; margin remotely and somewhat irregularly set with coarse teeth, some of them spinous; nervation strong, the midrib especially so, straight; secondaries numerous, 18 or 20 pairs, unequally spaced, emerging nearly at right angles, slightly curved upward, all camptodrome, curving near the borders, following them and entering the short teeth by oblique nervilles; areolation of minute polygonal meshes.

This description is drawn from the type specimens of *Quercus castaneopsis* Lesquereux and *Quercus castanoides* Newberry, both of which are preserved in the United States National Museum (Nos. 1575 and 7044, respectively). Leaves obviously of the same species were described independently by Lesquereux and Newberry, but as Lesquereux's publication antedates that of Newberry by a few months his name is selected as the one the species is to bear. Both noted the resemblance to leaves of *Castanea* or *Castanopsis*, and curiously enough both selected almost identical specific names.

Occurrence: Green River formation, Uinta (formerly incorrectly called Randolph) County Wyo. (type of *Quercus castaneopsis* Lesquereux); Green River, Wyo. (type of *Quercus castanoides* Newberry).

Order URTICALES.

Family ULMACEAE.

Planera inaequilateralis (Lesquereux) Knowlton, n. comb.

Alnites inaequilateralis Lesquereux, U. S. Geol. and Geog. Survey Terr. Bull., vol. 1, p. 381, 1875 [1876]; idem, Ann. Rept. for 1874, p. 307, 1876; U. S. Geol. Survey Terr. Rept., vol. 7 (Tertiary flora), p. 141, pl. 62, figs. 1-4, 1878.

Alnus inaequilateralis Lesquereux, U. S. Geol. Survey Terr. Rept., vol. 8 (Cretaceous and Tertiary floras), p. 151, 1883.

Planera variabilis Newberry, U. S. Nat. Mus. Proc., vol. 5, p. 508, 1882 [1883]; U. S. Geol. Survey Mon. 35, p. 83, pl. 66, figs. 5, 6 [not fig. 7], 1898.

Leaves evidently firm in texture, somewhat variable in size (4 to 8 centimeters long, 2.5 to 6 centimeters wide), broadly ovate or nearly oval, acute or rather obtusely acute at apex, strongly unequal-sided at the rounded or obtusely wedge-shaped base; margins crenulate-dentate; petiole short or absent; midrib strong, straight; secondaries mainly alternate, the lowest one on the broad side of the leaf usually with several outside branches, others considerably curved upward, ending in the low teeth or sending out minor branches that enter the teeth; nervilles at right angles to the secondaries, mainly unbroken.

This species as now accepted has had a rather complicated history. The original material was named and described, but not figured, by Lesquereux in 1875, under the name *Alnites inaequilateralis*. It was figured in the "Tertiary flora" (pl. 62, figs. 1-4) in 1878, but only two of the figured types (figs. 1 and 3) are now to be found in the collections of the United States National Museum. On the publication of the "Cretaceous and Tertiary floras," in 1883, Lesquereux changed the generic name to *Alnus*.

Subsequently C. A. White made a large collection of plants from the same region that had supplied Lesquereux's *Alnites* or *Alnus inaequilateralis*. This material was described by Newberry[62] in 1883 and contained several leaves that he named *Planera variabilis*. These were not figured, however, until 1898,[63] when it was at once apparent that at least two of his figured types (figs. 5, 6) were identical with Lesquereux's *Alnus inaequilateralis*.

Of course Lesquereux's specific name has priority, but a question arises as to the proper generic designation. It does not seem to me that these leaves can belong to *Alnus*, in which, so far as I know, the leaves are symmetrical at the base. I have transferred them to *Planera*, the genus adopted by Newberry, although it is to be admitted that they differ in some particulars from leaves of the monotypic living genus. The leaves of the living species, *Planera aquatica* Gmelin, are 5 or 6 centimeters long, 2 to 3 centimeters wide, unequally wedge-shaped or rounded at the base, and with the margins coarsely crenulate-serrate. They do not appear to have the lower secondary on the broad side of the leaf branched, but otherwise the difference is not great between these leaves and those of the fossil form under consideration.

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[62] Newberry, J. S., U. S. Nat. Mus. Proc., vol. 5, p. 508, 1883.

[63] U. S. Geol. Survey Mon. 35, p. 83, pl. 66, 1898.

Occurrence: Green River formation, Alkali stage station, Wyo. (type locality for *Alnus inaequilateralis* Lesquereux); Green River, Wyo. (type locality for *Planera variabilis* Newberry).

Family MORACEAE.

Ficus ungeri Lesquereux.

Ficus ungeri Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1871, Suppl., p. 7, 1872; U. S. Geol. Survey Terr. Rept., vol. 7 (Tertiary flora), p. 195, pl. 30, fig. 3, 1878; idem, vol. 8 (Cretaceous and Tertiary floras), p. 163, pl. 44, figs. 1-3, 1883.

The type of this species is the specimen figured in the "Tertiary flora" (pl. 30, fig. 3) and is No. 265 in the United States National Museum; it is very well described and figured. It came from Green River, Wyo., where it was found above the so-called fish beds.

The specimens figured in the "Cretaceous and Tertiary floras" (pl. 44, figs. 1-3) are all in the Museum collection (Nos. 1598, 1599, 1600). They came from Alkali stage station, which is about 30 miles north of Green River, Wyo.

Occurrence: Green River formation, Green River, Wyo., above fish beds (type); Alkali stage station, 30 miles north of Green River, Wyo.

Ficus wyomingiana Lesquereux.

Ficus wyomingiana Lesquereux, U. S. Geol. and Geog. Survey Terr. Bull., vol. 1, p. 387, 1875 [1876]; idem, Ann. Rept. for 1874, p. 314, 1876; U. S. Geol. Survey Terr. Rept., vol. 7 (Tertiary flora), p. 205, pl. 33, fig. 3, 1878.

The type and so far as known the only specimen of this species thus far found is in the United States National Museum collection (No. 289). It is fragmentary, lacking all of the upper portion and much of one side. As Lesquereux has said, this leaf is strikingly similar in general appearance to *Ficus pseudo-populus* Lesquereux, which was described from material collected at Evanston, Wyo., and which has since been found abundantly in the Raton formation of eastern Colorado and northeastern New Mexico and the Wilcox group of the Gulf region. It differs, however, in having the lateral ribs running nearly or quite to the apex of the blade and in the absence of any secondary branches, the space between the midrib and the lateral ribs as well as between the ribs and the margin being filled with numerous fine nervilles, which are nearly at right angles to the midrib.

Occurrence: Green River formation. Green River, Wyo.

Ficus tenuinervis Lesquereux.

Ficus tenuinervis Lesquereux, U. S. Geol. Survey Terr. Rept., vol. 8 (Cretaceous and Tertiary floras), p. 164, pl. 44, fig. 4, 1883.

This is a mere fragment of the basal part of a leaf that Lesquereux says is "oblong, or lanceolate, tripalmately nerved, rounded at base, entire." As it stands it is of comparatively little value, for it probably could not be identified again.

Occurrence: Green River formation, Alkali stage station, about 30 miles north of Green River, Wyo.

Order PROTEALES.

Family PROTEACEAE.

Lomatia? microphylla Lesquereux.

Lomatia microphylla Lesquereux, U. S. Geol. and Geog. Survey Terr. Bull., vol. 1, p. 389, 1875 [1876]; idem, Ann. Rept. for 1874, p. 346, 1876; U. S. Geol. Survey Terr. Rept., vol. 7 (Tertiary flora), p. 211, pl. 65, figs. 14, 15, 1878.

Described by Lesquereux as follows:

> Leaves very small, coriaceous, entire, linear-lanceolate, gradually narrowed from the middle to a point and in the same degree to the base; secondary veins simple, abruptly curving near the borders and following them or entering a marginal band.

The two figured specimens on which this species is based are not now known to be in existence. The smaller is about 2 centimeters long and the larger one only 3 centimeters long; the width is 2 to 4 millimeters.

The generic reference of these little leaves is extremely uncertain. It is to be doubted if they are correctly placed in *Lomatia*, though they somewhat resemble certain forms from the Swiss Miocene so referred by Heer. They suggest leaflets of *Mimosites*, of *Sophora*, or of *Sapindus*, such as *Sapindus angustifolius* Lesquereux.

Occurrence: Green River formation, near mouth of White River (emptying into Green River), Wyo.

Order THYMELEALES.

Family LAURACEAE.

Oreodaphne viridiflumensis Knowlton, n. sp.

Plate XXXVIII, figure 6.

Leaf coriaceous in texture, lanceolate, long wedge-shaped at the base, probably about equally narrowed above, about 12 centimeters long, 3 centimeters wide; margin perfectly entire; petiole very strong, 1 centimeter long, over 2 millimeters thick; midrib straight, very thick below and in the middle of the leaf but becoming thin above; secondaries somewhat irregular, lowest pair subopposite, thin, at an angle of about 40°, each running up for some distance and joining the secondary next above by a broad loop; next secondaries alternate, much stronger, each joining the one above by a loop far inside the margin, then with a series of large bows on the outer side; other secondaries similar, alternate, with a few intermediate secondaries joining the primary ones; nervilles very numerous, mostly broken, forming large rectangular areas, and filled with irregularly quadrangular areas and these again with still finer nerves.

This is a very fine species, but unfortunately it is represented by only the lower half of a leaf, though this is absolutely perfect. It may be known by its narrowly lanceolate shape, short, very thick petiole, unusually thick midrib, and the peculiar arching and branching secondaries.

In shape and size this species seems nearest to *Oreodaphne salinensis* Berry,[64] from the Wilcox group of Arkansas, but it differs in nervation, especially in the secondaries.

Occurrence: Green River formation, Rio Blanco County, about 40 miles southwest of Meeker, Colo., collected by D. E. Winchester, 1917.

Pimelea spatulata Knowlton, n. sp.

Plate XXXVII, figure 6

Leaf apparently firm in texture, narrowly spatulate, broadest in the upper third, whence it tapers to an acuminate apex and downward into a long, narrowly wedge-shaped base that merges with the petiole; nervation consisting of a relatively strong midrib and numerous thin, close, nearly parallel secondaries.

This little leaf, which is the only one noted in the collection, is very narrowly spatulate, about 17 millimeters long including the petiole, and about 4 millimeters wide. The base is so merged into the petiole that no more than a length of 4 millimeters can be considered as petiole.

This species seems to approach most closely *Pimelea delicatula* Lesquereux,[65] from the lake beds at Florissant, Colo., but differs in being much smaller and narrower and in the apparently somewhat thicker substance of the leaf.

Occurrence: Green River formation, oil shale, Cathedral Bluff, south of Little Tommies Draw, Rio Blanco County, about 20 miles west of Rio Blanco post office, Colo., collected by D. E. Winchester, 1917.

Order RANALES.

Family NYMPHAEACEAE.

Brasenia? antiqua Newberry.

Brasenia antiqua Newberry, U. S. Nat. Mus. Proc., vol. 5, p. 514, 1882 [1883]; U. S. Geol. Survey Mon. 35, p. 93, pl. 68, fig. 7, 1898.

The type of this species is No. 7018 of the United States National Museum collections and has been well described and figured by Newberry. No additional material has been procured, and hence there is nothing to make the identification either more or less certain.

Occurrence: Green River formation, Green River, Wyo.

Order ROSALES.

Family CRASSULACEAE?

Sedum? hesperium Knowlton, n. sp.

Plate XXXVII, figure 7.

Leaf apparently thick and fleshy, broadly lanceolate, widest near the middle, thence narrowed to the obtusely wedge-shaped base, obtuse and obscurely three-lobed at the apex; margin with two or three large teeth or lobes on each side; petiole very thick and stout; nervation peculiar, consisting of a rather strong midrib and numerous thin veins that arise in the lower part of the blade and spread out, a few of them forking to occupy the area between midrib and margin.

This form is represented by the single specimen figured. It is about 2.4 centimeters long and 1 centimeter wide, with the thick petiole

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[64] Berry, E. W., U. S. Geol. Survey Prof. Paper 91, p. 303, pl. 82, figs. 1, 2, 1917.

[65] Lesquereux, Leo, U. S. Geol. Survey Terr. Rept., vol. 8 (Cretaceous and Tertiary floras), p. 168, pl. 33, figs. 15, 16, 1883.

2 millimeters long. It is a very peculiar leaf, well characterized by the thick, evidently fleshy substance, obtuse, three-lobed apex, several large irregular lobes or teeth, and above all by the thick petiole, strong midrib, and thin, longitudinal veins.

I am uncertain as to its affinity. I have referred it with a question to *Sedum* on account of its fleshy character and resemblance to the living *Sedum telephioides* Michaux, but this resemblance may be only superficial. In any event it may be easily recognized in future, and more and better material may serve to place it more certainly.

Occurrence: Green River formation, Cathedral Bluff, south of Little Tommies Draw, 20 miles west of Rio Blanco post office, Rio Blanco County, Colo., collected by D. E. Winchester, 1917.

Family DRUPACEAE.

Amygdalus gracilis Lesquereux.

Amygdalus gracilis Lesquereux, U. S. Geol. Survey Terr. Rept., vol. 8 (Cretaceous and Tertiary floras), p. 199, pl. 40, figs. 12–15; pl. 44, fig. 6, 1883.

Penhallow, Report on Tertiary plants of British Columbia, p. 37, 1908.

Lesquereux characterized this species as follows:

> Leaves ovate-lanceolate, gradually narrowed to the acuminate point and in the same degree to the petiole; serrulate; lateral nerves at a more or less acute angle of divergence, much curved, camptodrome and reticulate along the borders.
>
> These fine leaves of solid membranaceous tissue average 7 centimeters long and 2 centimeters broad, with a slender petiole about 2 centimeters long. They are more or less distinctly minutely serrate; the nerves, open at base and much curved toward the borders, are joined by undulate nervilles nearly at right angles.

There appears to be much confusion regarding this species. It is based on five figured specimens, one of which (the original of pl. 40, fig. 12, of the "Cretaceous and Tertiary floras") is said to be in the Museum of Princeton University; the others should be in the United States National Museum, but only one can now be found. The original of figure 6 of Lesquereux's Plate XLIV is said to have come from Uinta County (formerly incorrectly called Randolph County), Wyo., but this specimen is missing. All the specimens shown on his Plate XL (figs. 12 to 15) are supposed to have come from Florissant, Colo., but the only specimen available (the original of fig. 13) is No. 1588 of the United States National Museum and is recorded as coming from Uinta County, Wyo., and this record is borne out by the matrix, which is clearly identical with the others from Uinta County and wholly unlike the Florissant material. This species has not been identified in any of the recently studied material from Florissant, and unless the missing specimens can ultimately be shown to have come from that locality it should be dropped from the Florissant list.

Two of the figured types of *Amygdalus gracilis* (pl. 40, figs. 14, 15) are poorly preserved fruits of which Lesquereux wrote as follows: "The fruits appear to belong to this genus and possibly to this species. The reference is of course hypothetical." Without access to the original specimens it is impossible to say much about them, and to judge from the figures alone there seems very little warrant for referring them to *Amygdalus* and absolutely none for connecting them with these leaves.

Occurrence: Green River formation. Uinta County (formerly erroneously called Randolph County), Wyo. All reference to the occurrence in the Florissant lake beds is extremely doubtful.

Family PAPILIONACEAE.

Dalbergia viridiflumensis Knowlton, n. sp.

Plate XL, figure 10.

Leaflet small, very thick in texture, obovate, strongly emarginate at the apex, wedge-shaped at the base, length 15 millimeters, width 11 millimeters; petiolule slender, 4 millimeters long; margin perfectly entire; midrib very strong, especially on the under side of the leaf, straight; secondaries thin but distinct, seven or eight pairs, at an acute angle, camptodrome, probably uniting with each other, but this point is obscure.

Unfortunately this specimen is the only one found in the collection, but it is so well marked that it can easily be recognized.

The genus *Dalbergia* is a large one, comprising over 80 species, mainly of the Tropics of both Old and New worlds. Many of the species have similar leaves and hence are hard to separate on this character alone. Among the 25 or more fossil species that have been described the one perhaps approached most closely by the present form is *Dalbergia eocenica* Berry,[66] from the Lagrange formation of Puryear, Tenn. *D. viridiflumensis* differs from that species, however, in being more regularly obovate and in being petiolulate instead of sessile.

Occurrence: Green River formation, Rio Blanco County, 20 miles west of Rio Blanco post office, Colo. (sec. 33, T. 4 S., R. 100 W.), collected by D. E. Winchester, 1917.

Dalbergia retusa Knowlton, n. sp.

Plate XL, figures 5, 6.

Leaflet thick in texture, elliptical, strongly retuse at the apex, abruptly rounded and equilateral at the base; petiolule short, very strong; midrib very strong; secondaries thin, immersed in the leaf substance, at a low angle of emergence, camptodrome, forming loops just inside the margin; fine nervation not discernible.

Unfortunately this species is represented only by a single leaflet with its counterpart, both of which have been figured, as there are certain features that can not be seen from either impression. It is regularly elliptical or slightly broader above the middle, being about 2.5 centimeters long and 2 centimeters wide. The very thick petiolule is 2 millimeters long. With the exception of the strong midrib the nervation is rather obscure but is thought to be as described above.

This little leaflet seems referable to the genus *Dalbergia* on the ground of being strongly retuse at the apex and slightly broader above the middle and having the type of nervation usual in the genus. It is, for instance, very similar to *Dalbergia eocenica* Berry,[67] from the Lagrange formation (in beds of Wilcox age) of western Tennessee, except as regards size. It also resembles certain leaflets from the Swiss Miocene described by Heer.[68]

Dalbergia retusa is also similar to *Simaruba eocenica* Berry[69] and *Canavalia eocenica* Berry,[70] both from the Wilcox group.

Occurrence: Green River formation, Little Duck Creek, Rio Blanco County, about 50 miles southwest of Meeker, Colo.; collected by D. E. Winchester, 1917.

Leguminosites alternans Lesquereux.

Leguminosites alternans Lesquereux, U. S. Geol. and Geog. Survey Terr. Bull., vol. 1, p. 388, 1875 [1876]; idem, Ann. Rept. for 1874, p. 315, 1876; U. S. Geol. Survey Terr. Rept., vol. 8 (Cretaceous and Tertiary floras), p. 202, 1883.

Leaflet lanceolate, narrowed to the sessile base (point broken), apparently tapering and acute; secondary veins close, numerous, 15 pairs in a space of 2.5 centimeters, with indeterminate shorter tertiary veins anastomosing by crossing veinlets; areolation obsolete.

This leaf is comparable to a *Dalbergia* or a *Podogonium* by its nervation; its form, especially the narrowed base, is comparable to *Cassia*.

The above description by Lesquereux is all that has been written concerning this species. The type or types are not known to be in existence, and as it was never figured its status must be considered more or less unsatisfactory.

Occurrence: Green River formation, near mouth of White River (emptying into Green River), Wyo.

Sophora coloradensis Knowlton, n. sp.

Plate XXXVII, figures 14-16; Plate XL, figure 11.

Leaflets rather thin in texture, ovate or ovate-elliptical, obtuse and rounded at the apex, abruptly rounded or obtusely wedge-shaped at the base; petiolule short, stout; midrib moderately strong, straight; secondaries few, mainly opposite, thin, at a low angle, camptodrome, forming broad loops, especially in the upper part.

The smallest of the several leaflets referred to this species (fig. 14) is about 2.25 centimeters long and 1.8 centimeters wide, and the largest (fig. 16) about 4 centimeters long and 2 centimeters wide. In both these leaflets the base is obtusely wedge-shaped, but in another example (fig. 16) the base is much more abruptly rounded—in fact, almost truncate. It is nearly 2.5 centimeters wide and was probably not far from 5 centimeters long.

This species suggests some of the forms of *Sophora wilcoxiana* Berry,[71] from the Wilcox group, but is more ovate or ovate-elliptical and has more arched secondaries.

Occurrence: Green River formation, Little Duck Creek, Rio Blanco County, about 50 miles southwest of Meeker, and Camp Gulch, 25 miles northwest of De Beque, Colo., collected by D. E. Winchester, 1917.

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[66] Berry, E. W., U. S. Geol. Survey Prof. Paper 91, p. 245, pl. 53, figs. 1, 2, 1916.

[67] Idem.

[68] Heer, Oswald, Flora tertiaria Helvetiae, vol. 3, pl. 133, 1859.

[69] Op. cit., pl. 54, fig. 7.

[70] Op. cit., pl. 53, fig. 3.

[71] Berry, E. W., U. S. Geol. Survey Prof. Paper 91, p. 241, pl. 47, figs. 1-13, 1916.

2 millimeters long. It is a very peculiar leaf, well characterized by the thick, evidently fleshy substance, obtuse, three-lobed apex, several large irregular lobes or teeth, and above all by the thick petiole, strong midrib, and thin, longitudinal veins.

I am uncertain as to its affinity. I have referred it with a question to *Sedum* on account of its fleshy character and resemblance to the living *Sedum telephioides* Michaux, but this resemblance may be only superficial. In any event it may be easily recognized in future, and more and better material may serve to place it more certainly.

Occurrence: Green River formation, Cathedral Bluff, south of Little Tommies Draw, 20 miles west of Rio Blanco post office, Rio Blanco County, Colo., collected by D. E. Winchester, 1917.

Family DRUPACEAE.

Amygdalus gracilis Lesquereux.

Amygdalus gracilis Lesquereux, U. S. Geol. Survey Terr. Rept., vol. 8 (Cretaceous and Tertiary floras), p. 199, pl. 40, figs. 12-15; pl. 44, fig. 6, 1883.

Penhallow, Report on Tertiary plants of British Columbia, p. 37, 1908.

Lesquereux characterized this species as follows:

> Leaves ovate-lanceolate, gradually narrowed to the acuminate point and in the same degree to the petiole; serrulate; lateral nerves at a more or less acute angle of divergence, much curved, camptodrome and reticulate along the borders.
>
> These fine leaves of solid membranaceous tissue average 7 centimeters long and 2 centimeters broad, with a slender petiole about 2 centimeters long. They are more or less distinctly minutely serrate; the nerves, open at base and much curved toward the borders, are joined by undulate nervilles nearly at right angles.

There appears to be much confusion regarding this species. It is based on five figured specimens, one of which (the original of pl. 40, fig. 12, of the "Cretaceous and Tertiary floras") is said to be in the Museum of Princeton University; the others should be in the United States National Museum, but only one can now be found. The original of figure 6 of Lesquereux's Plate XLIV is said to have come from Uinta County (formerly incorrectly called Randolph County), Wyo., but this specimen is missing. All the specimens shown on his Plate XL (figs. 12 to 15) are supposed to have come from Florissant, Colo.; but the only specimen available (the original of fig. 13) is No. 1588 of the United States National Museum and is recorded as coming from Uinta County, Wyo., and this record is borne out by the matrix, which is clearly identical with the others from Uinta County and wholly unlike the Florissant material. This species has not been identified in any of the recently studied material from Florissant, and unless the missing specimens can ultimately be shown to have come from that locality it should be dropped from the Florissant list.

Two of the figured types of *Amygdalus gracilis* (pl. 40, figs. 14, 15) are poorly preserved fruits of which Lesquereux wrote as follows: "The fruits appear to belong to this genus and possibly to this species. The reference is of course hypothetical." Without access to the original specimens it is impossible to say much about them, and to judge from the figures alone there seems very little warrant for referring them to *Amygdalus* and absolutely none for connecting them with these leaves.

Occurrence: Green River formation. Uinta County (formerly erroneously called Randolph County), Wyo. All reference to the occurrence in the Florissant lake beds is extremely doubtful.

Family PAPILIONACEAE.

Dalbergia viridiflumensis Knowlton, n. sp.

Plate XL, figure 10.

Leaflet small, very thick in texture, obovate, strongly emarginate at the apex, wedge-shaped at the base, length 15 millimeters, width 11 millimeters; petiolule slender, 4 millimeters long; margin perfectly entire; midrib very strong, especially on the under side of the leaf, straight; secondaries thin but distinct, seven or eight pairs, at an acute angle, camptodrome, probably uniting with each other, but this point is obscure.

Unfortunately this specimen is the only one found in the collection, but it is so well marked that it can easily be recognized.

The genus *Dalbergia* is a large one, comprising over 80 species, mainly of the Tropics of both Old and New worlds. Many of the species have similar leaves and hence are hard to separate on this character alone. Among the 25 or more fossil species that have been described the one perhaps approached most closely by the present form is *Dalbergia eocenica* Berry,[66] from the Lagrange formation of Puryear, Tenn. *D. viridiflumensis* differs from that species, however, in being more regularly obovate and in being petiolulate instead of sessile.

Occurrence: Green River formation, Rio Blanco County, 20 miles west of Rio Blanco post office, Colo. (sec. 33, T. 4 S., R. 100 W.), collected by D. E. Winchester, 1917.

Dalbergia retusa Knowlton, n. sp.

Plate XL, figures 5, 6.

Leaflet thick in texture, elliptical, strongly retuse at the apex, abruptly rounded and equilateral at the base; petiolule short, very strong; midrib very strong; secondaries thin, immersed in the leaf substance, at a low angle of emergence, camptodrome, forming loops just inside the margin; fine nervation not discernible.

Unfortunately this species is represented only by a single leaflet with its counterpart, both of which have been figured, as there are certain features that can not be seen from either impression. It is regularly elliptical or slightly broader above the middle, being about 2.5 centimeters long and 2 centimeters wide. The very thick petiolule is 2 millimeters long. With the exception of the strong midrib the nervation is rather obscure but is thought to be as described above.

This little leaflet seems referable to the genus *Dalbergia* on the ground of being strongly retuse at the apex and slightly broader above the middle and having the type of nervation usual in the genus. It is, for instance, very similar to *Dalbergia eocenica* Berry,[67] from the Lagrange formation (in beds of Wilcox age) of western Tennessee, except as regards size. It also resembles certain leaflets from the Swiss Miocene described by Heer.[68]

Dalbergia retusa is also similar to *Simaruba eocenica* Berry [69] and *Canavalia eocenica* Berry,[70] both from the Wilcox group.

Occurrence: Green River formation, Little Duck Creek, Rio Blanco County, about 50 miles southwest of Meeker, Colo.; collected by D. E. Winchester, 1917.

Leguminosites alternans Lesquereux.

Leguminosites alternans Lesquereux, U. S. Geol. and Geog. Survey Terr. Bull., vol. 1, p. 388, 1875 [1876]; idem, Ann. Rept. for 1874, p. 315, 1876; U. S. Geol. Survey Terr. Rept., vol. 8 (Cretaceous and Tertiary floras), p. 202, 1883.

Leaflet lanceolate, narrowed to the sessile base (point broken), apparently tapering and acute; secondary veins close, numerous, 15 pairs in a space of 2.5 centimeters, with indeterminate shorter tertiary veins anastomosing by crossing veinlets; areolation obsolete.

This leaf is comparable to a *Dalbergia* or a *Podogonium* by its nervation; its form, especially the narrowed base, is comparable to *Cassia*.

The above description by Lesquereux is all that has been written concerning this species. The type or types are not known to be in existence, and as it was never figured its status must be considered more or less unsatisfactory.

Occurrence: Green River formation, near mouth of White River (emptying into Green River), Wyo.

Sophora coloradensis Knowlton, n. sp.

Plate XXXVII, figures 14-16; Plate XL, figure 11.

Leaflets rather thin in texture, ovate or ovate-elliptical, obtuse and rounded at the apex, abruptly rounded or obtusely wedge-shaped at the base; petiolule short, stout; midrib moderately strong, straight; secondaries few, mainly opposite, thin, at a low angle, camptodrome, forming broad loops, especially in the upper part.

The smallest of the several leaflets referred to this species (fig. 14) is about 2.25 centimeters long and 1.8 centimeters wide, and the largest (fig. 16) about 4 centimeters long and 2 centimeters wide. In both these leaflets the base is obtusely wedge-shaped, but in another example (fig. 16) the base is much more abruptly rounded—in fact, almost truncate. It is nearly 2.5 centimeters wide and was probably not far from 5 centimeters long.

This species suggests some of the forms of *Sophora wilcoxiana* Berry,[71] from the Wilcox group, but is more ovate or ovate-elliptical and has more arched secondaries.

Occurrence: Green River formation, Little Duck Creek, Rio Blanco County, about 50 miles southwest of Meeker, and Camp Gulch, 25 miles northwest of De Beque, Colo., collected by D. E. Winchester, 1917.

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[66] Berry, E. W., U. S. Geol. Survey Prof. Paper 91, p. 245, pl. 53, figs. 1, 2, 1916.

[67] Idem.

[68] Heer, Oswald, Flora tertiaria Helvetiae, vol. 3, pl. 133, 1859.

[69] Op. cit., pl. 54, fig. 7.

[70] Op. cit., pl. 53, fig. 3.

[71] Berry, E. W., U. S. Geol. Survey Prof. Paper 91, p. 241, pl. 47, figs. 1-13, 1916.

Family MIMOSACEAE.

Mimosites coloradensis Knowlton, n. sp.

Plate XL, figures 1-3.

Leaves pinnate; leaflets opposite, sessile or nearly so, linear or linear-lanceolate, slightly unequal-sided, rather abruptly rounded at the base, acuminate or obtuse at the apex; margin perfectly entire; nervation, except for a strong midrib, mainly obsolete.

This species is represented by one leaf that has the petiole preserved complete—2.5 centimeters long—with parts of two sessile leaflets, as well as by a considerable number of detached leaflets. The smallest is about 8 millimeters long and the longest 28 millimeters long. The width is 2 or 3 millimeters. The leaflets are evidently thick, as hardly anything but the midrib is discernible.

This species is very closely related to and perhaps identical with *Mimosites linearifolius* Lesquereux,[72] from the lake beds at Florissant, Colo., but appears to differ in being less fulcate and less sharply pointed. In one of the leaflets there is a slight indication that the midrib is excurrent.

This species is similar to certain of the smallest leaflets of *Mimosites variabilis* Berry,[73] from beds of Wilcox age in the Lagrange formation of western Tennessee and Kentucky, and from the Wilcox group of Mississippi, but these are more nearly elliptical with obtuse base and apex.

Occurrence: Green River formation, spring on Little Duck Creek, about 50 miles southwest of Meeker, Rio Blanco County, Colo., collected by D. E. Winchester, 1917.

Order GERANIALES.

Family SIMARUBACEAE.

Ailanthus longe-petiolata Lesquereux.

Ailanthus longe-petiolata Lesquereux. U. S. Geol. Survey Terr. Rept., vol. 8 (Cretaceous and Tertiary floras), p. 197, pl. 40, figs. 6, 7, 1883.

Both figured types of this species are preserved in the United States National Museum, the leaflet being No. 1586 and the fruit No. 1587. No additional examples of either leaves or fruit have been collected, and it may stand as left by Lesquereux.

Occurrence: Green River formation, Uinta County (formerly wrongly called Randolph County), Wyo.

Order SAPINDALES.

Family SAPINDACEAE.

Sapindus dentoni Lesquereux.

Sapindus dentoni Lesquereux, U. S. Geol. and Geog. Survey Terr. Bull., vol. 1, p. 388, 1875 [1876]; idem, Ann. Rept. for 1874, p. 315, 1876; U. S. Geol. Survey Terr. Rept., vol. 7 (Tertiary flora), p. 265, pl. 44, figs. 2-4, 1878.

Described by Lesquereux as follows:

> Leaflets with entire or slightly undulate borders, lanceolate [6 or 7 centimeters long, 1.1 to 1.7 centimeters wide], gradually tapering to a long acumen, rounded to the [slightly unequal-sided] base and narrowed to a short petiole [1 centimeter long]; lateral nerves close, parallel, nearly straight to the borders, where they abruptly curve.

Unfortunately the type specimens of this species are now lost; at least, they do not appear to be in the United States National Museum, and their location is not known. Lesquereux compares these "leaflets" with those of *Sapindus angustifolius* Lesquereux, from the Florissant lake beds, but there are sufficient differences to separate them. They can also be compared with leaves of *Eucalyptus? americanus* Lesquereux, as figured in the "Tertiary flora," Plate LIX, figures 11 and 12, but as we have only the drawings to go by it is perhaps best to leave them under *Sapindus*.

Occurrence: Green River formation, near the mouth of White River, Utah, collected by William Denton, for whom the species is named.

Sapindus obtusifolius Lesquereux.

Sapindus obtusifolius Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1873, p. 419, 1874; U. S. Geol. Survey Terr. Rept., vol. 7 (Tertiary flora), p. 266, pl. 49, figs. 8-11, 1878; idem, vol. 8 (Cretaceous and Tertiary floras), pp. 181, 235, pl. 48, figs. 5-7, 1885.

The type locality of *Sapinus obtusifolius* is about 8 miles southeast of Green River, Wyo., where it was found in association with *Musophyllum complicatum* Lesquereux and a fragment of a leaf of *Carpinus grandis*. The four figured types are all preserved in the United States National Museum (Nos. 392-395).

Subsequently Lesquereux[74] stated that he found a single specimen with the leaflets attached in material from the lake beds at Florissant, Colo. I have not seen this specimen, but Lesquereux says it is even smaller than that of figure 8 of the "Tertiary flora."

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[72] Lesquereux, Leo, U. S. Geol. Survey Terr. Rept., vol. 7 (Tertiary flora), p. 300, pl. 59, fig. 7, 1878; idem, vol. 8 (Cretaceous and Tertiary floras), p. 203, pl. 37, figs. 10-13, 1883.

[73] Berry, E. W., U. S. Geol. Survey Prof. Paper 91, p. 227, pl. 45, figs. 6-11, 1916.

[74] Lesquereux, Leo, U. S. Geol. Survey Terr. Rept., vol. 8 (Cretaceous and Tertiary floras), p. 181, 1883.

In the "Cretaceous and Tertiary floras" Lesquereux[75] also reported this species from the Fort Union formation of North Dakota. The present location of the specimens so designated is not known, but they were very well figured, and from the figures it appears that, although they resemble the originals of *S. obtusifolia*, they are probably a different species. The largest leaflet is 11.5 centimeters long and 4 centimeters wide, and it seems questionable to place them with leaflets only 1 to 1.5 centimeters long. It will require a considerable series of connecting forms to show the relationship.

The recent collections from western Colorado contain a number of leaflets that are to be referred to *Sapindus obtusifolius*, but as they add nothing to our knowledge of the species they have not been figured.

Occurrence: Green River formation, 8 miles southeast of Green River, Wyo., collected by Leo Lesquereux, 1873; spring on Little Duck Creek, about 50 miles southwest of Meeker, Rio Blanco County, Colo., collected by D. E. Winchester, 1917.

Sapindus winchesteri Knowlton, n. sp.

Plate XXXVIII, figure 1.

Leaflet very large, 14.5 centimeters long and 3.5 centimeters wide, lanceolate, strongly unequal-sided, broadest at about one-third of the length above the base, whence it narrows gradually to the rather obtuse apex and downward to the wedge-shaped base; nervation strong, especially the midrib, with about 16 pairs of alternate, irregularly spaced camptodrome secondaries, which arise at low angles, curve upward slightly, and arch just inside the margin, each joining the one next above; there are a few intermediate secondaries and a strong secondary nervation.

This splendid species is represented by the nearly perfect leaflet figured and a number of smaller fragments. It is one of the largest, if not indeed the largest species thus far described in this country. It somewhat resembles *Sapindus affinis* Newberry,[76] an extremely abundant form in the Fort Union, but it is more than twice the size of the ordinary leaflets of that species and is much more obtuse at the apex and has a much stronger nervation. It is more like certain leaflets from the Fort Union of the Yellowstone Park identified as *Sapindus affinis*,[77] though it is much larger and has a stronger nervation.

The only species of *Sapindus* heretofore noted in the Green River formation is *S. dentoni* Lesquereux,[78] but this is a small-leaved form wholly unlike the present one.

Occurrence: Green River formation, oil shale, Smith ranch, on Greasewood Creek, about 40 miles southwest of Meeker, Rio Blanco County, Colo., collected by D. E. Winchester, 1917.

Family ANACARDIACEAE.

Rhus lesquereuxii Knowlton and Cockerell.

Rhus lesquereuxii Knowlton and Cockerell, U. S. Geol. Survey Bull. 696, p. 552, 1919.

Rhus acuminata Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1871, Suppl., p. 8, 1872; U. S. Geol. Survey Terr. Rept., vol. 8 (Cretaceous and Tertiary floras), p. 194, pl. 42, figs. 14–17, 1883. [Homonym, De Candolle, 1865.]

The type locality for *Rhus acuminata* Lesquereux is Green River, Wyo., above the so-called fish beds, but the type specimen is not known to be in the collection of the United States National Museum and is presumably lost. It has not subsequently been found in the Green River formation, the figured specimens being from the lake beds at Florissant, Colo. (U. S. Nat. Mus. Nos. 1871–1874). Its status as a Green River species is therefore open to question.

Occurrence: Green River formation, Green River, Wyo., above the fish beds.

Rhus variabilis (Newberry) Knowlton, n. comb.

Planera variabilis Newberry, U. S. Nat. Mus. Proc., vol. 5, p. 508, 1883; U. S. Geol. Survey Mon. 35, p. 83, pl. 66, fig. 7 [not figs. 5 and 6, which=*Planera inaequilateralis* (Lesquereux) Knowlton], 1898.

Leaf firm in texture, lanceolate, about 6 centimeters long and 2 centimeters wide, acute at the apex, evenly wedge-shaped (at about 45° angle) at the base; margin coarsely and somewhat irregularly toothed; petiole stout, at least 1 centimeter long; midrib strong; secondaries numerous, irregularly spaced, parallel, at a low angle, ending in the margin.

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[75] U. S. Geol. Survey Terr. Rept. vol. 8, p. 235, pl. 48, figs. 5–7, 1883.

[76] Newberry, J. S., U. S. Geol. Survey Mon. 35, p. 116, pl. 30, fig. 1, 1898.

[77] Knowlton, F. H., U. S. Geol. Survey Mon. 32, pt. 2, pl. 102, figs. 1–3, 1899.

[78] Lesquereux, Leo, U. S. Geol. Survey Terr. Rept., vol. 7 (Tertiary flora), p. 265, pl. 64, figs. 2–4, 1883.

This species is based on one of the figured types of Newberry's *Planera variabilis*. At the time it was made a type Newberry apparently had some misgiving, for he said:

> Possibly future collections will prove that the narrower, more rigid form with the deeply cut and acute serrations and parallel, nearly straight lateral veins, shown in figure 7, belongs to a different species; but in the very large number of *Planera* leaves before me it is impossible to make any division without making several. They are therefore all grouped together for the present.

He further adds that he had at his disposal a large number of specimens that seem to connect the two forms, but as these are not available it appears best to consider them as distinct.

It may also be pointed out that the leaf under discussion seems to be congeneric with *Myrica* (now *Rhus*) *nigricans* Lesquereux [79] and for this reason has been transferred to the genus *Rhus*. It is more nearly lanceolate and has rather coarser marginal teeth, but otherwise does not greatly differ. It is not contained in any of the more recent collections.

Occurrence: Green River formation, Green River, Wyo. (one of the types of *Planera variabilis*), collected by C. A. White.

Rhus nigricans (Lesquereux) Knowlton, n. comb.

Myrica nigricans Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1871, Suppl., p. 6, 1872; U. S. Geol. Survey Terr. Rept., vol. 7 (Tertiary flora), p. 132, pl. 17, figs, 9–12, 1878.

Myrica nigricans was described as follows by Lesquereux:

> Leaves nearly sessile, alternate, oblong or linear-lanceolate, acuminate, round-cuneate to the base, obtusely dentate; nervation camptodrome.

He supplemented this description with the following remarks:

> The leaves of this species are like those of the former [*Myrica undulata?* Heer], only narrower, all narrowly lanceolate or linear-lanceolate, narrowed to a long acumen, and about sessile or with a very short petiole about 1 millimeter long. They are more or less unequal at the base, distantly obtusely dentate in the middle.

Three of the figured types of this species are preserved in the United States National Museum (figs. 9–11, Nos. 401a, 150, 151) and are seen to be fragmentary. The specimen shown in figure 9 is evidently the one on which is based the statement that the leaves are simple and alternate, but a close view of the original disclosed that there was a piece of the matrix covering the point of attachment of one leaf, and when this was removed they were found to be practically opposite. They are slightly unequal-sided and in my opinion are leaflets of a pinnately compound leaf. This conclusion of necessity removes the form from *Myrica*, which has simple leaves, and it seems to justify their reference to *Rhus*. The other types are also slightly unequal-sided and are probably conspecific. The margin is undulate-toothed in these three-figured specimens, but another figure (fig. 10a) shows the margin with sharp teeth.

Occurrence: Green River formation, Green River, Wyo., northwest of station and above the fish beds, collected by F. V. Hayden, 1868.

Rhus myricoides Knowlton, n. sp.

Plate XXXVII, figures 9–11.

Leaflets of firm texture, narrowly lanceolate, prolonged above into a slender acuminate tip, abruptly narrowed and unequal-sided at the base; margin entire for a short distance at the base, thence strongly toothed, the teeth deltoid, pointing upward; petiolule short, stout; midrib relatively strong, especially below; secondaries and intermediate secondaries numerous, mainly alternate, thin, emerging at a low angle, slightly curved upward, craspedodrome, the stronger ones entering the teeth, the others at intermediate points; finer nervation obscure.

This species is represented by a number of very well preserved leaflets, three of the most nearly perfect of which have been figured. The length was apparently from about 5.5 to 6.5 centimeters and the width approximately 1 centimeter. The petiolule is very short, hardly exceeding 2 milimeters.

This species is undoubtedly most closely related to *Rhus nigricans* (*Myrica nigricans* Lesquereux[80])—in fact, they may be identical. *Rhus myricoides* appears to differ in being more strongly toothed and to a minor degree in the nervation.

Occurrence: Green River formation, Smith ranch, on Greasewood Creek, about 40 miles southwest of Meeker, Rio Blanco County, Colo., collected by D. E. Winchester, 1917.

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[79] Lesquereux, Leo, U. S. Geol. Survey Terr. Rept., vol. 7 (Tertiary flora), p. 132, pl. 17, figs. 9–12, 1878.

[80] Lesquereux, Leo, U. S. Geol. Survey Terr. Rept., vol. 7 (Tertiary flora), p. 132, pl. 17, figs. 9–12, 1878.

Family CELASTRACEAE.

Euonymus flexifolius Lesquereux.

Euonymus flexifolius Lesquereux, U. S. Geol. Survey Terr. Rept., vol. 8 (Cretaceous and Tertiary floras), p. 183, pl. 38, fig. 13, 1883.

This splendid species is described as follows by Lesquereux:

> Leaves large [16.5 centimeters long, 5 centimeters wide], ovate-acuminate from an oval base, flexures at the apex, narrowed from the middle to the petiole, sharply deeply serrate; secondary nerves alternate, equidistant and parallel, camptodrome.

The single type specimen is the only one thus far obtained. It is No. 1585 of the United States National Museum collection.

Occurrence: Green River formation, Uinta County (formerly incorrectly called Randolph county), Wyo.

Family ACERACEAE.

Acer lesquereuxii Knowlton.

Acer lesquereuxii Knowlton, U. S. Geol. Survey Bull. 152, p. 26, 1898.

Acer indivisum Lesquereux, U. S. Geol. Survey Terr. Rept., vol. 8 (Cretaceous and Tertiary floras), p. 180, pl. 36, figs. 6, 9, 1883. [Homonym, Weber, 1852.]

Lesquereux's original description reads as follows:

> Leaves small, of thin texture, round-truncate in outline, five-nerved and five-lobed; lobes entire, sharply acuminate; sinuses broad, entire or dentate in the middle; petiole comparatively long, inflated under the point of attachment.
>
> The leaves are 5.5 centimeters broad between the points of the upper lobes and only 4 centimeters long from the top of the petiole, which is 5.5 centimeters long.

The type of the leaf on which this species is based is preserved in the United States National Museum (No. 1582), but the fruits also made cotypes are not to be found here. This species has not been found in subsequent collections.

Occurence: Green River formation, Uinta County (formerly wrongly called Randolph County), Wyo., collected by F. V. Hayden.

Family ILICACEAE.

Ilex? affinis Lesquereux.

Ilex? affinis Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1871, Suppl., p. 8, 1872; U. S. Geol. Survey Terr. Rept., vol. 7 (Tertiary flora), p. 270, pl. 50, figs. 2, 3, 1878.

This species is based on two examples, both of which were figured by Lesquereux, and both are in the United States National Museum collection (Nos. 400, 401). They are fragmentary, as he states, both having lost the upper portion. Lesquereux says:

> These leaves, inequilateral at base, seem like pinnules of a compound leaf. The midrib is thick, the secondary veins numerous, parallel, inequidistant, and, at an open angle of divergence, either enter the point of the teeth and, by their branches, follow the borders in festoons or are truly camptodrome, with nervilles passing up from the back of the curves into the teeth.

Lesquereux questioned the generic reference of these leaves, and it is more than probable that they should be placed elsewhere, but they are so fragmentary that affinities are interpreted with difficulty, and it may be best to leave them for the present in *Ilex*.

Occurrence: Green River formation, Green River, Wyo., above the fish beds.

Ilex maculata Lesquereux.

Ilex maculata Lesquereux, U. S. Geol. Survey Terr. Rept., vol. 8 (Cretaceous and Tertiary floras), p. 186, pl. 44, fig. 5, 1883.

The single type specimen (No. 1603, U. S. Nat. Mus.) is the only one recorded of this species. It is poorly preserved and the generic reference is open to more or less question.

Occurrence: Green River formation, Alkali stage station, about 30 miles north of Green River, Wyo.

Ilex vyomingiana Lesquereux.

Ilex vyomingiana Lesquereux, U. S. Geol. Survey Terr. Rept., vol. 7 (Tertiary flora), p. 270, pl. 50, fig. 1, 1878.

The type of this species (No. 399, U. S. Nat. Mus.) is so fragmentary and obscure that it is difficult to interpret. Its reference to *Ilex* may well be questioned, but as no other relationship can reasonably be suggested it is left as placed by Lesquereux.

Occurrence: Green River formation, Green River, Wyo., above the fish beds.

Order RHAMNALES.

Family RHAMNACEAE.

Zizyphus longifolia Newberry.

Plate XL, figure 7.

Zizyphus longifolia Newberry, U. S. Nat. Mus. Proc., vol. 5, p. 513, 1882 [1883]; U. S. Geol. Survey Mon. 35, p. 119, pl. 65, figs. 3, 4 [not fig. 5, which= *Zizyphus cinnamomoides* Lesquereux], 1898.

Leaves evidently very firm in texture, 7.5 to 9.5 centimeters long, about 1.5 centimeters wide, lanceolate, rather abruptly rounded to the obtusely wedge-shaped base, long pointed at apex; margins waved or more or less distinctly toothed; petiole slender, at least 2 centimeters long; midrib well defined from base to summit; lateral nerves or ribs arising with the petiole and nearly as strong, passing up close to the margin for nearly one-half the length of the blade, then joining the lowest pair of secondaries on the midrib; secondaries three or four pairs, alternate, curving upward, forming a festoon near the margin; nervilles finely reticulated.

Newberry figured three specimens as the types of this species, and all are preserved in the United States National Museum (Nos. 7020, 7021, 7022). Of these, two (figs. 3 and 4 of his plate) agree with the above description and are here taken as typical of *Zizyphus longifolia.* The other specimen is obviously different—in fact, it agrees with *Zizyphus cinnamomoides* Lesquereux,[81] as Newberry himself pointed out, and it is transferred to that species. Newberry states that *Zizyphus longifolia* is very abundant in the collections submitted to him and is usually associated in the beds with *Lygodium* and *Acrostichum.*

In the collections from western Colorado I find several leaves of this species, one of which I have figured. It is a narrow leaf about 8 centimeters long and 1.6 centimeters wide. Its margin is provided with remote, low, rounded teeth. The nervation is that described and figured for the species.

Occurrence: Green River formation, Green River, Wyo.; oil shale at Smith ranch, on Greasewood Creek, about 40 miles southwest of Meeker, Colo., collected by D. E. Winchester, 1917.

Zizyphus cinnamomoides (Lesquereux) Lesquereux.

Zizyphus cinnamomoides (Lesquereux) Lesquereux, U. S. Geol. Survey Terr. Rept., vol. 7 (Tertiary flora), p. 277, pl. 52, figs. 7, 8, 1878.

Zizyphus longifolia Newberry, U. S. Geol. Survey Mon. 35, pl. 65, fig. 5 [not figs. 3, 4], 1898.

Ceanothus cinnamomoides Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1871, p. 289, 1872.

Leaves of firm texture, 5 to 9 centimeters long, 1.5 to 2.5 centimeters wide, oblong or ovate-lanceolate, broadest at or a little below the middle, wedge-shaped below, prolonged above into a slender point; margin more or less crenate from a point well above the base of the blade; triple-nerved from the top of the petiole, the midrib straight, with four or five pairs of thin secondaries in the upper part; lateral nerves or ribs closer to the margin than the midrib, joining the lowest pair of secondaries; finer nervation irregularly recticulate.

Lesquereux based this species on two leaves from Green River shale, both of which lack the upper portion. Later Newberry received material from the same locality and from it he characterized his *Zizyphus longifolia.* Of the three types figured by Newberry two are alike and are long, narrow, three-nerved leaves, but the other is clearly identical with Lesquereux's *Zizyphus cinnamomoides* and has been transferred to it.

Ward[82] identified a single small leaf from the Fort Union formation near Glendive, Mont., with Lesquereux's *Zizyphus cinnamomoides,* but it has a very different nervation and must be excluded.

Occurrence: Green River formation, Green River, Wyo.

Family VITACEAE.

Cissus parrottiaefolia Lesquereux.

Cissus parrottiaefolia Lesquereux, U. S. Geol. and Geog. Survey Terr. Bull., vol. 1, p. 388, 1875 [1876]; idem, Ann. Rept. for 1874, p. 314, 1876; U. S. Geol. Survey Terr. Rept., vol. 7 (Tertiary flora), p. 239, pl. 40, figs. 15–17; pl. 42, fig. 1, 1878.

The three types of this species supposed to be from Green River, Wyo., are in the United States National Museum (Nos. 343, 344, 345). The matrix is rather soft yellowish sandstone, quite unlike anything from the Green River beds with which I am familiar, and there is doubt as to the propriety of continuing this as a Green River species.

Occurrence: Green River formation, Green River, Wyo., west of station.

Parthenocissus tertiaria (Lesquereux) Knowlton, n. comb.

Ampelopsis tertiaria Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1871, Suppl., p. 7, 1872; U. S. Geol. Survey Terr. Rept., vol. 7 (Tertiary flora), p. 242, pl. 43, fig. 1, 1878.

The type and only specimen of this species found is preserved in the United States National Museum (No. 361) and has been fairly well characterized by Lesquereux. The two leaflets on the left-hand side are represented as broken, but really they pass under one of the type specimens of *Juglans schimperi* and can not be excavated without destroying the *Juglans*.

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[81] Lesquereux, Leo, U. S. Geol. Survey Terr. Rept., vol. 7 (Tertiary flora), p. 277, pl. 52, figs. 7, 8, 1878.

[82] Ward, L. F., U. S. Geol. Survey Sixth Ann. Rept., for 1884–85, p. 554, pl. 52, fig. 3, 1886; idem, Bull. 37, p. 74, pl. 33, fig. 7, 1887.

Occurrence: Green River formation, Green River, Wyo., above the fish beds.

Order MYRTALES.

Family MYRTACEAE?

Eucalyptus? americanus Lesquereux.

Plate XXXIX, figures 1-3.

Eucalyptus? americana Lesquereux, U. S. Geol. Survey Terr. Rept., vol. 7 (Tertiary flora), p. 296, pl. 59, figs. 11, 12, 1878.

Eucalyptus americanus Lesquereux, U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1871, Suppl., p. 7, 1872.

Apocynophyllum scudderi Lesquereux, U. S. Geol. Survey Terr. Rept., vol. 8, (Cretaceous and Tertiary floras), p. 172, pl. 45, *A*, figs. 1-5, 1883.

Salix angusta Al. Braun? Newberry, U. S. Geol. Survey Mon. 35, p. 54, pl. 65, fig. 2, 1898.

Leaves coriaceous in texture, narrowly lanceolate, gradually tapering upward from below the middle into a long, narrow acumen and narrowed in nearly the same degree to the base, slightly unequal-sided and very slightly undulate; petiole very thick, about 1 centimeter long; midrib extremely thick, especially below, where it merges into the petiole; lateral nerves thin, immersed in the substance of the leaf, emerging at angles of 30° to 45°, about 5 millimeters apart, irregular, many of them with intermediate nerves that join others at various distances below the margin; the main nerves all terminate in a strong, continuous intramarginal vein which is about 1 millimeter from the margin; finer nervation consisting of very thin, irregular veins oblique to the principal veins.

These are splendid leaves, clearly coriaceous or leathery in texture. There is considerable range in size, the larger ones being nearly 13 centimeters long and about 2 centimeters wide and the smaller ones 6 or 8 centimeters long and 1.5 centimeters wide. The petiole, which is enlarged at the point of attachment, does not exceed 1 centimeter in length.

The types of *Eucalyptus? americana* as figured by Lesquereux in the "Tertiary flora" (pl. 59, figs. 11, 12) are preserved in the United States National Museum (Nos. 489, 489a). The best preserved leaf is a nearly perfect one 12 centimeters long and 1.5 centimeters wide. The other was a larger leaf, fully 2 centimeters wide, but lacks the upper portion. The nervation is that above described.

In 1883 Lesquereux[83] described some rather fragmentary leaves from Alkali station under the name *Apocynophyllum scudderi*. These specimens are in the United States National Museum (Nos. 1605-1609) and are before me. Although they are somewhat smaller than the types of *Eucalyptus? americanus*, they clearly belong with them. They have the same coriaceous texture, very thick midrib, thin, immersed lateral veins, and continuous intramarginal vein. They seem properly to be referable to *Eucalyptus? americanus*.

The leaf figured by Newberry[84] as *Salix angusta* Al. Braun? is also preserved in the United States National Museum (No. 7023) and clearly belongs to *Eucalyptus? americanus*. It comes from Green River and is said by Newberry to be exceedingly common, "some slabs of the rock being quite covered with the leaves." Newberry does not mention the strongly marked intramarginal vein, though it is shown in his figure and, of course, in the specimen.

The propriety of referring these leaves to the genus *Eucalyptus* may perhaps be open to question, as it is doubted by some that this genus ever reached America. Be that as it may, their facies—long, narrow, coriaceous leaves with exceedingly thick midrib and deeply immersed veins running into a strong intramarginal vein—is distinctly that of *Eucalyptus*, and I have retained them as left by Lesquereux. There are some other things that are to be considered in this connection. Thus Lesquereux in the original discussion of his *Eucalyptus? americanus* compares them to species of *Tricera* from Cuba. This is a euphorbiaceous genus with narrow leaves having a nervation similar to that of *Eucalyptus*. I have not seen these leaves and so can not say anything as to their probable affinity with the Green River leaves under consideration.

Berry[85] has described as *Ficus myrtifolius* some narrow leaves from the Wilcox group that he says are nearest to Lesquereux's *Apocynophyllum scudderi*. The Wilcox leaves are of about the same size and shape as Lesquereux's species and have the thick midrib and well-marked intramarginal vein, but the lateral veins are almost at right angles and are more numerous than in the Green River leaves.

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[83] Lesquereux, Leo, U. S. Geol. Survey Terr. Rept., vol. 8 (Cretaceous and Tertiary floras), p. 172, pl. 45, *A*, figs. 1-5, 1883.

[84] Newberry, J. S., U. S. Geol. Survey Mon. 35, p. 54, pl. 65, fig. 2, 1898.

[85] Berry, E. W., U. S. Geol. Survey Prof. Paper 91, p. 205, pl. 30, figs. 1-3, 1916.

Occurrence: Green River formation, Green River, Wyo., above the fish beds, types collected about 1870 by F. V. Hayden, others collected by C. A. White and still later by L. F. Ward; Alkali stage station, about 30 miles north of Green River, type locality for *Apocynophyllum scudderi*, collected by F. V. Hayden; Cathedral Bluff, south of Little Tommies Draw, about 20 miles west of Rio Blanco post office, Rio Blanco County, Colo., in sec. 35, T. 4 S., R. 100 W., Colo., and above oil shale, head of trail up ridge between Carr and Bushy creeks, Garfield County, Colo., collected by D. E. Winchester, 1917.

Order UMBELLALES.

Family ARICACEAE.

Aralia wyomingensis Knowlton and Cockerell.

Plate XXXIX, figure 4; Plate XL, figure 12.

Aralia wyomingensis Knowlton and Cockerell, U. S. Geol. Survey Bull. 696, p. 88, 1919.

Aralia macrophylla Newberry, U. S. Nat. Mus. Proc., vol. 5, p. 513, 1882 [1883]; U. S. Geol. Survey Mon. 35, p. 121, pl. 67, fig. 1; pl. 68, fig. 1, 1898. [Homonym, Lindley, 1844.]

This species was described by Newberry as follows:

> Leaves large, long-petioled, palmately five-parted from the middle upward, divisions conical in outline, sometimes entire, often remotely, occasionally coarsely toothed; nervation strong and regular; the midrib of the divisions strong and straight, those from the second lateral lobes springing from near the bases of the first lateral lobes; secondary nerves numerous, distinct, curved gently upward; where the margins are entire, partially camptodrome; where dentate, terminating in the teeth; tertiary nerves anastomosing to form quadrangular and very numerous areoles.

In speaking of the occurrence of these leaves, Newberry says:

> In the localities where they are found the leaves of *A. macrophylla* [*A. wyomingensis*] are exceedingly abundant, sometimes matted together so as to obscure their outlines. These show that they vary in size, in the number of lobes, and in the character of the margins, occasionally one occurring which is only three-lobed, while almost all are five, and the margins are sometimes nearly entire, while in other leaves they are all strongly, even spinously, dentate. The leaves vary from 3 to 12 inches in length, and the lobes are sometimes long and narrow, in others much broader.

The two figured types of this species, both preserved in the United States National Museum, are large leaves, hence the name *macrophylla* was very appropriate, but in Newberry's discussion of the species he states that they range in length from 3 to 12 inches.

In the collections recently made in western Colorado there are a number of leaves that must be referred to *Aralia wyomingensis*. Two of these have been figured. One (Pl. XL, fig. 12) is a very small leaf only 6 centimeters long and a little over 7 centimeters wide, with slender petiole 2 centimeters long. The other (Pl. XXXIX, fig. 4) is somewhat larger, probably 12 or 14 centimeters long and some 12 centimeters broad.

The leaf from Bridger Pass, Wyo., described by Lesquereux[86] under the name *Aralia? gracilis*, may belong here, but it is so fragmentary that it can not be compared fully with *Aralia wyomingensis*.

Occurrence: Green River formation, Green River, Wyo. (types), collected by C. A. White; Cathedral Bluff, south of Little Tommies Draw, about 20 miles west of Rio Blanco post office, Rio Blanco County, Colo.; collected by D. E. Winchester, 1917.

Order ERICALES.

Family ERICACEAE.

Andromeda delicatula Lesquereux.

Andromeda delicatula Lesquereux, U. S. Geol. Survey Terr. Rept., vol. 8 (Cretaceous and Tertiary floras), p. 175, pl. 34, figs. 10, 11, 1883.

The two type specimens on which this fine species is based are preserved in the United States National Museum (Nos. 1580, 1581) and have been very well described and figured by Lesquereux. The species has not been since collected in the Green River formation, but has been reported from the supposed upper Eocene of British Columbia and the Fort Union formation of the Bull Mountains, Mont.; the latter is perhaps doubtful.

Occurrence: Green River formation, Uinta County (formerly wrongly called Randolph County), Wyo.; Eocene, Tranquille River, British Columbia; Fort Union formation, Bull Mountains, Mont.

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[86] Lesquereux, Leo, U. S. Geol. Survey Terr. Rept., vol. 7 (Tertiary flora), p. 236, pl. 39, fig. 1, 1878.

Order RUBIALES.

Family CAPRIFOLIACEAE.

Sambucus? winchesteri Knowlton, n. sp.

Plate XL, figures 8, 9.

This flower is very small, having a spread of only about 4 millimeters. In the exact center is a circular mass of black carbonaceous substance that is without any observable structure. The flower is perfectly regular, with five oblong obtuse petals, alternating with which are the five stamens. At first sight it appears that the petals are free, but as the actual insertion of both petals and stamens is obscured by the central carbonaceous mass, it is possible that the corolla is slightly gamopetalous—in fact, if the identification given is correct the petals must be slightly united. The petals are about 1.7 millimeters long and 0.8 millimeter broad, and each has three relatively strong veins which run from the base nearly to the apex. The stamens are slightly more than half the length of the petals and have large anthers.

A great many flowers have been studied in comparison with this fossil flower, and all things considered it seems to approach *Sambucus* most closely. This genus has the calyx tube ovoid or turbinate, adnate to the ovary, with its limb three to five toothed, and the corolla rotate or slightly campanulate, regular, and usually five-lobed; the five stamens are inserted on the base of the corolla.

The fossil flower under consideration seems to agree fairly well with the above diagnosis, at least so far as can be made out, but as there are some points that can not be settled with certainty, the generic reference has been questioned. This flower is named in honor of the collector.

Occurrence: Green River formation, oil shale, Rio Blanco County, about 40 miles southwest of Meeker, Colo.; collected by D. E. Winchester.

Order CAMPANULALES.

Family COMPOSITAE.

Achaenites cichorioides Knowlton, n. sp.

Plate XL, figure 4.

Achene narrowly obconical, about 7 millimeters long, 2 millimeters in diameter at the top, strongly ribbed (apparently four-ribbed) with several (at least three) thinner intermediate striae; pappus simple, apparently sparse, not barbed, about 7 millimeters long.

This little achene, the only one found in the collection, is surprisingly well preserved considering the delicate nature of some of its parts. The achene itself was evidently hard and resistant and apparently has suffered little distortion. It is strongly ribbed or ridged, especially in the lower part, and from the disposition of these ridges it seems probable that they were four in number, but this is of course somewhat uncertain. The pappus is certainly simple and without obvious barbs; it was at least as long as the achene. It appears to occupy a single ring around the outer edge of the flat-topped achene.

It is perhaps hazardous to attempt a close comparison of this fossil achene with those of any living species, though it may be pointed out that it seems to fall within the family Cichoriaceae, whence the specific name adopted for it. It is, for instance, suggestive of the achenes in certain species of *Nabalus*, *Hieracium*, etc., but more evidence will be needed before it can be placed in any living genus. It is believed to be the first composite achene from this country to be described.

A word may be said as to the selection of the generic name for this achene. The genus *Achaenites* was established by Braun[87] in 1851, with *A. ungeri* as the type species. It was not figured at that time, but in the Neues Jahrbuch for 1854 Braun described and figured it. It is an oblong, long-beaked achene with a plumose pappus, and came from the Swiss Miocene.

In 1859, when Heer [88] came to the consideration of the numerous fruits of the Compositae found in the Miocene of Switzerland, he established the genus *Cypselites*, with which he merged Braun's *Achaenites*, notwithstanding the fact that the latter had some eight years priority. Heer described and figured no less than 19 species under his *Cypselites*, which he stated probably really belong to a number of different genera. None of them seem to be very close to the Green River species under discussion.

The law of priority does not sanction the substitution of one genus for another without reason, and therefore *Achaenites* will have to be restored for Heer's species of *Cypselites*. Moreover, *Achaenites* is more appropriate than *Cypselites* for these obvious achenes.

Occurrence: Green River formation, above rich oil shale, Camp Gulch, about 25 miles northwest of De Beque, Colo., collected by D. E. Winchester, 1917.

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[87] Braun, Al., in Stizenberger, Ernst, Uebersicht der Versteinerungen des Grossherzogthums Baden, p. 83, 1851.

[88] Heer, Oswald, Flora tertiaria Helvetiae, vol. 3, p. 2, 1859.

PLANTS OF UNCERTAIN POSITION.

Antholithes improbus Lesquereux.

Antholithes improbus Lesquereux, U. S. Geol. Survey Terr. Rept., vol. 8 (Cretaceous and Tertiary floras), p. 204, pl. 40, figs. 20, 21, 1883.

Both the figured types of this peculiar organism are preserved in the United States National Museum (No. 1666). I am not able to interpret them any more satisfactorily than Lesquereux did.

Occurrence: Green River formation, Uinta County (formerly wrongly called Randolph County), Wyo.

Carpolithus caryophylloides Knowlton, n. sp.

Plate XXXVII, figure 13.

The collections from western Colorado made by Winchester include the little specimen here figured. It is apparently a dry capsule, ovoid in shape, about 5 millimeters long and 4 millimeters in diameter at the base, and with a slender pedicel 2 millimeters long. It appears to be made on the plan of five, and is split down about half its length, each segment being apparently bifid at the apex and with a strong central rib or ridge.

This specimen is so small and indifferently preserved that it is difficult of interpretation. From the fact that it is not much crushed or distorted the inference is drawn that it was a dry capsule that had discharged its seeds when entombed. It may be split down for more than half its length, but it does not seem to be.

It is of course more or less hazardous to attempt to refer this capsule to a living genus or even family, and consequently it has been placed in the form genus and convenient catch-all *Carpolithus*, until it can be more definitely assigned. However, it may be pointed out that this specimen undoubtedly has a strong albeit superficial likeness to the capsule of certain Caryophyllaceae, as, for example, the genus *Lychnis*. The several species of *Lychnis* have a globular or ovoid one-celled capsule that opens by the splitting apart of the ten or five segments, which are often two-cleft at the apex. The capsule of *Lychnis dioica* Linné is especially suggested by this Green River capsule.

Occurrence: Green River formation, Smith ranch, on Greasewood Creek, about 40 miles southwest of Meeker, Rio Blanco County, Colo,. collected by D. E. Winchester, 1917.

Carpites viburni Lesquereux.

Carpites viburni Lesquereux, U. S. Geol. and Geog. Survey Terr. Bull., vol. 1, p. 382, 1875 [1876]; U. S. Geol. Survey Terr. Rept., vol. 7 (Tertiary flora), p. 305, pl. 60, figs. 26, 26a, 1878.

The original description by Lesquereux reads as follows:

> Seeds or nutlets cordate, obtuse, 5 to 7 millimeters long, 3 or 4 millimeters broad, convex, grooved in the middle from the point to the base, surrounded by a membranaceous pellicle, the remains of an apparently fleshy outer envelope.
>
> They resemble seeds of a similar kind which I have found in great quantity at Golden [Colo.] and referred to the genus *Viburnum*.

A complication has arisen concerning the locality from which this species came. At the time it was named and described it was distinctly stated by Lesquereux to have come from Alkali stage station, 30 miles north of Green River, Wyo., but three years later, when it was described and figured in the "Tertiary flora," the locality was given as Black Buttes, Wyo. The type specimen is fortunately preserved in the United States National Museum (No. 494), and it is there recorded in Lesquereux's handwriting as coming from Black Buttes. There is reason to believe, however, that the original assignment is correct, and that it really came from Alkali station and hence from the Green River formation, and not from Black Buttes. The matrix is a fine-grained yellowish sandstone, similar in character to that of other specimens from Alkali station, and, moreover, the temporary label affixed to the specimen by Lesquereux is an oval, blue-bordered "sticker" identical with those used on other specimens from Alkali station, whereas those on the specimens from Black Buttes are of a different shape and bordered with red. No specimens from Black Buttes were described by Lesquereux in the report in which the specimens from Alkali station were described, and, further, it seems inherently improbable that a mixture would occur when a collection from a given locality was first considered. It is believed that this species actually came from Alkali station, and it will be so regarded hereafter.

Occurrence: Green River formation, Alkali stage station, 30 miles north of Green River, Wyo. [incorrectly accredited to Black Buttes, Wyo.].

Carpites newberryana Knowlton, n. sp.

Juglans occidentalis Newberry, U. S. Geol. Survey Mon. 35, p. 34, pl. 66, figs. 4a–4c, 1898 [not figs. 1–4].

This species was characterized by Newberry as follows:

> Fruit small, elongated, somewhat prismatic; divisions of the envelope lenticular in outline, narrow, thin.
>
> The fruit, of which fortunately one specimen was found in immediate contact with the leaves, is small, marked with raised lines, elongate in form, and resembles more the fruit of

Carya olivaeformis [*Hicoria pecan* Britten?] than any other of our living species. It might be inferred from the size of the nut and its elongated form that it was immature, but near it lies a segment of the envelope which has apparently exfoliated at maturity. As only one specimen of the fruit has been discovered, it is possible that it does not represent the average size and form.

Newberry placed this form under *Juglans*, although he expressly states that it clearly belongs to *Hicoria*, but justified this disposition on the ground of the wider limit of the old genus *Juglans*. He also stated that the fruit is in "immediate contact" with the leaves, but a study of the types, which are preserved in the United States National Museum, shows that they are merely associated with leaves of *Juglans occidentalis* on the same piece of matrix but are not in organic comnection with them or in a position that suggests such union. It therefore seems necessary to transfer it to the genus to which it apparently belongs. if it has been correctly interpreted, and to give it a new name.

The three type specimens have been very carefully studied. The original of figure 4a is about 16 millimeters long and 7 millimeters broad near the middle. It stands on a short, stout pedicel, which is somewhat expanded and probably cup-shaped and in which rests the fruit. It has a deep longitudinal median furrow and on either side a slender ridge that nearly or quite disappears before reaching the apex. There is very little other structure or marking between the ribs or ridges.

On the same piece of matrix as the specimen just described, about 1 centimeter from it, is the specimen shown in Newberry's figure 4b. It is about 15 millimeters long and about 4 millimeters wide. When viewed in the position in which it was drawn for Newberry's figure it appears to be concave, much as one of the segments of the exocarp of *Hicoria* would appear, but when the orientation is reversed it is found to be convex.

The third specimen (Newberry's fig. 4c) is 19 millimeters long and about 7 millimeters wide. It appears to sit in the excavated apex of the pedicel as described for the first specimen mentioned. It has a single furrow a little to one side of the middle, and there is some evidence of the presence of a thin exocarp or something of the kind on one side.

It seems to me very unlikely that these specimens can belong to *Hicoria*, and they certainly can not belong to *Juglans*. Under the circumstances it appears best to refer them to the noncommittal *Carpites* until additional material may help to place them more definitely.

Occurrence: Green River formation, Green River, Wyo. (described and figured as fruit of *Juglans occidentalis* Newberry; types, U. S. Nat. Mus., Nos. 7031, 7032).

Carpites inquirenda Knowlton, n. sp.

Plate XXXVIII, figure 4.

The collection from western Colorado includes a small fruit that I am not able to place biologically. It is elliptical in outline, about 6 millimeters long and 5 millimeters broad, and has an inner dark nucleus, also elliptical, about 3 millimeters long and 2 millimeters broad. This inner part has a slight projection at one end, but whether this is the apex or the point of attachment has not been determined. Similarly it is impossible with present knowledge to determine whether the outer portion is to be interpreted as a wing, or whether the whole thing is a monospermous capsule.

This organism is so little understood that it might perhaps better be omitted altogether, yet it is a very definite entity that someone may be able to interpret correctly.

Occurrence: Green River formation, oil shale, Cathedral Bluff, south of Little Tommies Draw, Rio Blanco County, Colo., collected by D. E. Winchester, 1917.

Phyllites winchesteri Knowlton, n. sp.

Plate XXXVIII, figure 2.

The collections from the oil shales of western Colorado include the present nearly perfect little leaf. It seems unfortunate to be compelled to describe so fine a specimen under the name *Phyllites*, but I am wholly unable to suggest a generic name with any degree of assurance. It is a linear-lanceolate leaf about 3 centimeters long and 6 millimeters wide. The upper part is narrowed for fully a third the length of the blade into a sharp-pointed apex; below it is more abruptly narrowed to the rather thick petiole, which is nearly 1 centimeter in length. The margin is perfectly entire. The nervation is peculiar. In the middle and upper portions there is some indication of a thin midrib, but in the basal portion the midrib can not be differentiated. Five or six nerves of equal strength arise below the base of the blade and spread out to divide equally the area of the lower third of the leaf, with little indication that the middle one is the stronger. In the middle and upper portions even these nerves appear to be immersed in the leaf substance.

Occurrence: Green River formation, Rio Blanco County, 20 miles west of Rio Blanco post office, Colo., in sec. 33, T. 4 S., R. 100 W., collected by D. E. Winchester, 1917.

Phyllites fremonti Unger.

Phyllites fremonti Unger, Genera et species plantarum fossilium, p. 503, 1850.

Knowlton, U. S. Geol. Survey Prof. Paper 108, p. 94, 1917.

Leaf of a dicotyledonous plant (?) Hall, in Frémont, Report of the exploring expedition to the Rocky Mountains in 1842, etc., Appendix B, p. 306, pl. 11, fig. 4, 1845.

This species has had an interesting history. It was collected by Frémont in 1843 on his celebrated exploring expedition to the Rocky Mountains and beyond and was included in a collection of plants from the vicinity of what is now Cumberland, Wyo. The plants from this locality were long supposed to be of Jurassic age but are now known to belong to the Colorado group (Frontier formation).[89] The plant under consideration was placed by Hall, who described the collection, at the end of his paper with the following remarks:

> Locality in the neighborhood of the specimens containing the preceding fossils and regarded by Capt. Frémont as belonging to the same formation. The rock containing them is a soft or very partially indurated clay, very unlike the hard and brittle mass containing the other species.

The probability that it did not come from the vicinity of the Cumberland locality is further strengthened by the chance statement "Fr. Aug. 17, and No. 201 of collection," which appears to mean that it was collected on Friday, August 17, whereas the others are recorded under the date August 19. Frémont's itinerary for the earlier date indicates that on that day the expedition encamped on Blacks Fork of Green River, some 40 miles east of the locality reached on August 19. In the low hills bordering the stream he found "strata containing handsome and very distinct vegetable fossils." This locality is presumably in the Green River formation, and if the above reasoning is correct it appears to dispose of the reference of this species to the Colorado flora. The type specimen is now lost, and hence a study of the matrix in which it was preserved is impossible.

This species was named and described as *Phyllites fremonti* from Hall's figure. Unger fell into the usual error of ascribing it to Oregon, as the expedition went to "Oregon and north California." The above history has been given at some length for the purpose of setting forth the somewhat unsatisfactory status of this species and thus preventing future misunderstanding.

Occurrence: Green River formation (?), Blacks Fork of Green River, Wyo.

Nordenskiöldia borealis Heer.

Nordenskiöldia borealis Heer, Flora fossilis arctica, vol. 2, Abt. 3, p. 65, pl. 7, figs. 1-13, 1870.

Newberry, U. S. Geol. Survey Mon. 35, p. 137, pl. 68, figs. 4-6, 1898.

Whatever the nature of this organism may be there seems no doubt that it is identical with that described and figured by Heer.

Occurrence: Green River formation, Green River, Wyo.

Phyllites coloradensis Knowlton, n. sp.

Plate XXXVIII, figure 3.

Leaf compound; rachis strong, straight; leaflets opposite, lanceolate, unequal-sided, sharply acuminate at the apex, narrowed to the base and decurrent in a narrow wing that reaches the leaflets next below; margin perfectly entire; nervation obscure, consisting of a fairly strong midrib and apparently with thin secondaries at an angle of about 40°, but this is uncertain.

This species is represented by the single specimen figured, which shows three pairs of opposite leaflets. The lower pairs are about 3 centimeters long and 8 or 9 millimeters wide; the next pairs are about 2 centimeters long and 5 or 6 millimeters wide, and the terminal (or uppermost pair preserved) leaflets are only 5 millimeters wide.

I am uncertain as to the generic reference of this specimen. The shape and nervation of the leaflets strongly suggest *Sapindus*, and it may be recalled that in certain of the living species, such as *Sapindus saponaria* Linné, the rachis is winged between the leaflets, as indeed it is in some living species of *Rhus*, but in the present specimen it is the basal portion of the leaflet that is prolonged as a narrow wing down the rachis.

Occurrence: Green River formation, spring on Little Duck Creek, about 50 miles southwest of Meeker, Rio Blanco County, Colo., collected by D. E. Winchester, 1917.

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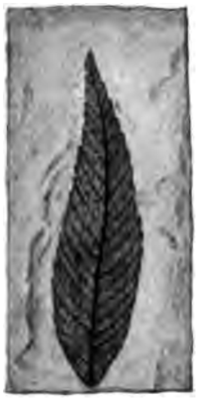
[89] Knowlton, F. H., U. S. Geol. Survey Prof. Paper 108, pp. 73-107, 1917.

PLATES XXXVI–XL.

PLATE XXXVI.

FIGURES 1-3. *Myrica praedrymeja* Knowlton. From Greasewood Creek, about 40 miles southwest of Meeker, Colo. U. S. Nat. Mus. Nos. 36557, 36558, 36559. (See p. 157.)

4. *Danaea coloradensis* Knowlton. From Rio Blanco County, Colo., about 40 miles southwest of Meeker. Pinnule, × 2. U. S. Nat. Mus. No. 36560. (See p. 150.)
5. *Danaea fendleri* Underwood. Living species from Trinidad, introduced for comparison. Segment of fruiting pinnule, × 6.
6. *Pontederites hesperia* Knowlton. From Greasewood Creek, about 40 miles southwest of Meeker, Colo. U. S. Nat. Mus. No. 36561. (See p. 154.)
7. *Lygodium kaulfussii* Heer. From Little Duck Creek, Rio Blanco County, Colo. U. S. Nat. Mus. No. 36582. (See p. 149.)
8. *Caenomyces eucalyptae* Knowlton, on leaves of *Eucalyptus? americanus* Lesquereux. From Little Duck Creek, about 50 miles southwest of Meeker, Colo. × 2. For natural size, see Plate XXXIX, figure 2. U. S. Nat. Mus. No. 36589. (See p. 148.)
9. Same as figure 8, × 6. Figure retouched.
10. *Caenomyces sapindicola* Knowlton, on leaflet of *Sapindus winchesteri* Knowlton. From Greasewood Creek, about 40 miles southwest of Meeker, Colo. × 4. For natural size, see Plate XXXVIII, figure 1. Figure retouched. U. S. Nat. Mus. No. 36590. (See p. 148.)



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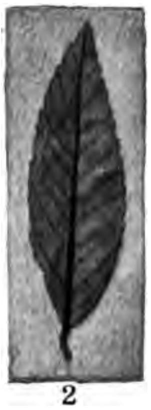

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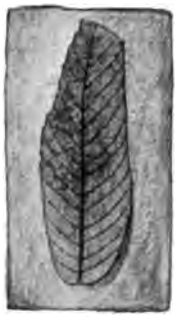

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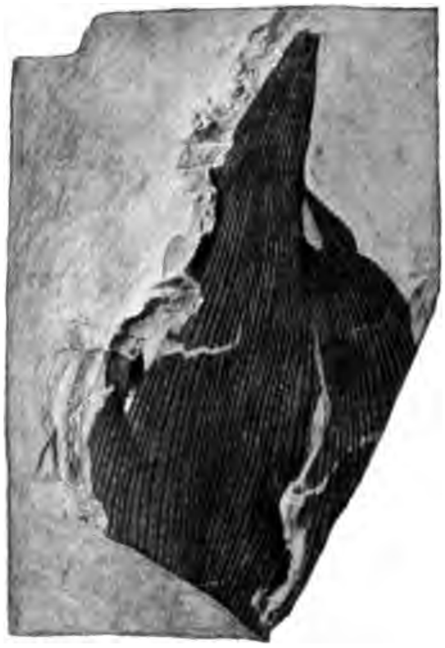

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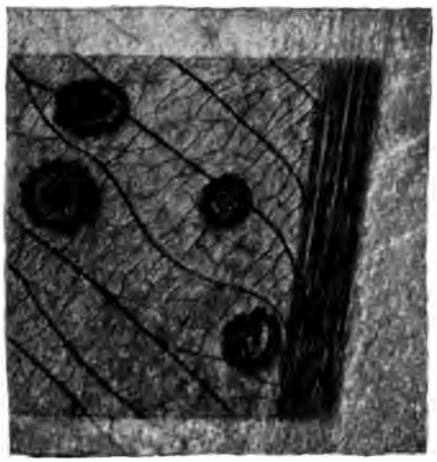

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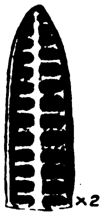

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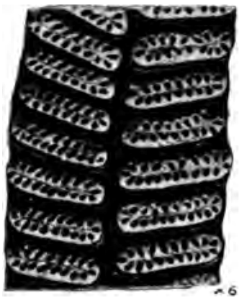

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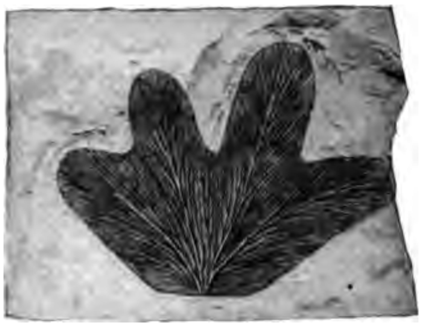

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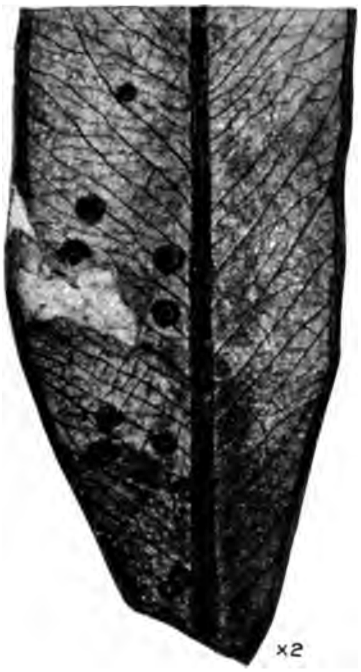

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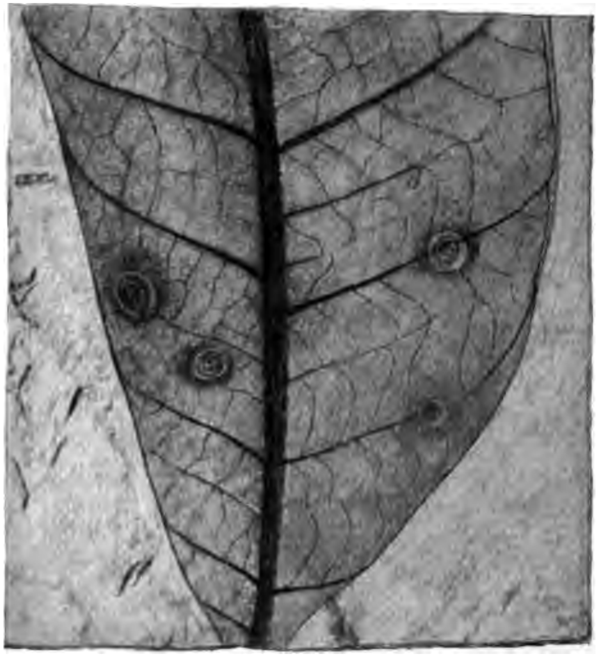

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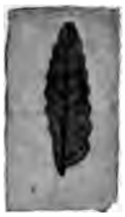
FLORA OF THE GREEN RIVER FORMATION.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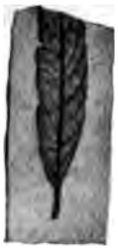
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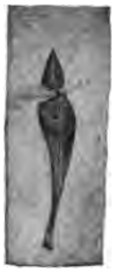
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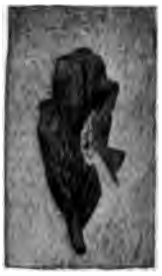
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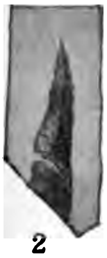
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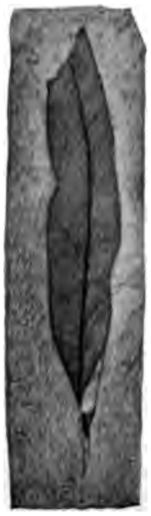
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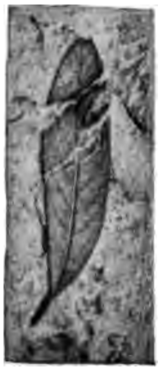
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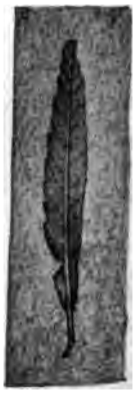
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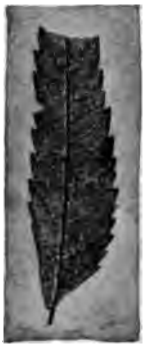
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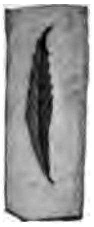
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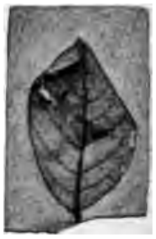
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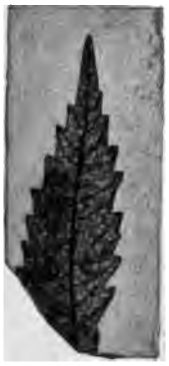
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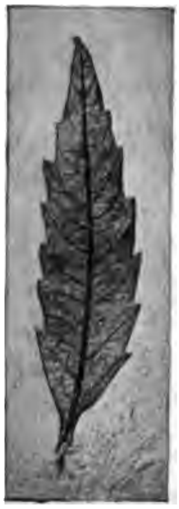
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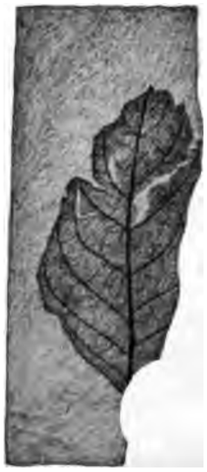
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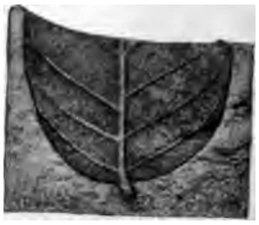
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FLORA OF THE GREEN RIVER FORMATION.

PLATE XXXVII.

FIGURE 1. *Comptonia? anomala* Knowlton. From Greasewood Creek, about 40 miles southwest of Meeker, Colo. U. S. Nat. Mus. No. 36563. (See p. 158.)

2. *Myrica* sp. From Cathedral Bluff, 20 miles west of Rio Blanco post office, Colo. U. S. Nat. Mus. No. 36564. (See p. 157.)

3-5. *Salix* sp. From Rio Blanco County, about 40 miles southwest of Meeker, Colo. U. S. Nat. Mus. Nos. 36565, 36566, 36567. (See. p. 156.)

6. *Pimelea spatulata* Knowlton. From Cathedral Bluff, about 20 miles west of Rio Blanco post office, Colo. U. S. Nat. Mus. No. 36568. (See p. 163.)

7. *Sedum? hesperium* Knowlton. From Cathedral Bluff, about 20 miles west of Rio Blanco post office, Colo. U. S. Nat. Mus. No. 36569. (See p. 163.)

8. *Salix linearis* Knowlton. From Rio Blanco County, Colo., about 20 miles west of Rio Blanco post office. U. S. Nat. Mus. No. 36570. (See p. 155.)

9-11. *Rhus myricoides* Knowlton. From Greasewood Creek, about 40 miles southwest of Meeker, Colo. U. S. Nat. Mus. Nos. 36571, 36572, 36573. (See p. 168.)

12. *Myrica minuta* Knowlton. From Greasewood Creek, about 40 miles southwest of Meeker, Colo. U. S. Nat. Mus. No. 36574. (See p. 157.)

13. *Carpolithus caryophylloides* Knowlton. From Greasewood Creek, 40 miles southwest of Meeker, Colo. U. S. Nat. Mus. No. 36575. (See p. 174.)

14-16. *Sophora coloradensis* Knowlton. Figures 14 and 16 from Little Duck Creek, Rio Blanco County, Colo., about 50 miles southwest of Meeker; figure 15 from Camp Gulch, 25 miles northwest of De Beque, Colo. U. S. Nat. Mus. Nos. 36576, 36577, 36578. (See p. 165.)

PLATE XXXVIII.

FIGURE 1. *Sapindus winchesteri* Knowlton. From Greasewood Creek, about 40 miles southwest of Meeker, Colo. U. S. Nat. Mus. No. 36579. (See p. 167.)

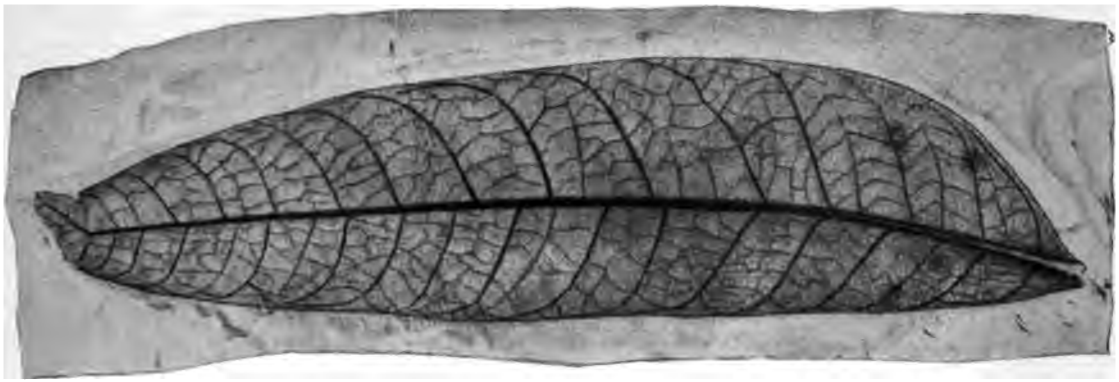
2. *Phyllites winchesteri* Knowlton. From Cathedral Bluff, about 20 miles west of Rio Blanco post office, Cool. U. S. Nat. Mus. No. 36580. (See p. 175.)

3. *Phyllites coloradensis* Knowlton. From Little Duck Creek, about 50 miles southwest of Meeker, Colo. U. S. Nat. Mus. No. 36581. (See p. 176.)

4. *Carpites inquirenda* Knowlton. From Cathedral Bluff, about 20 miles west of Rio Blanco post office, Colo. U. S. Nat. Mus. No. 36582. (See p. 175.)

5. *Juglans winchesteri* Knowlton. From Cathedral Bluff, about 20 miles west of Rio Blanco post office, Colo. U. S. Nat. Mus. No. 36583. (See p. 160.)

6. *Oreodaphne viridiflumensis* Knowlton. From Rio Blanco County, Colo., about 40 miles southwest of Meeker. U. S. Nat. Mus. No. 36584. (See p. 163.)



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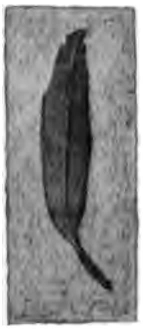

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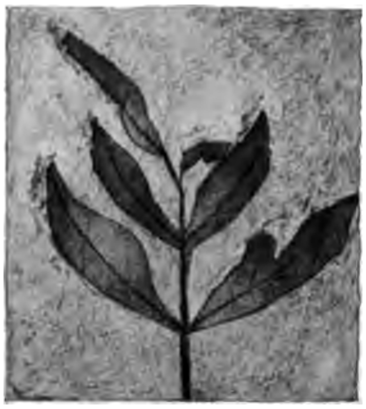

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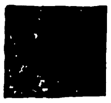

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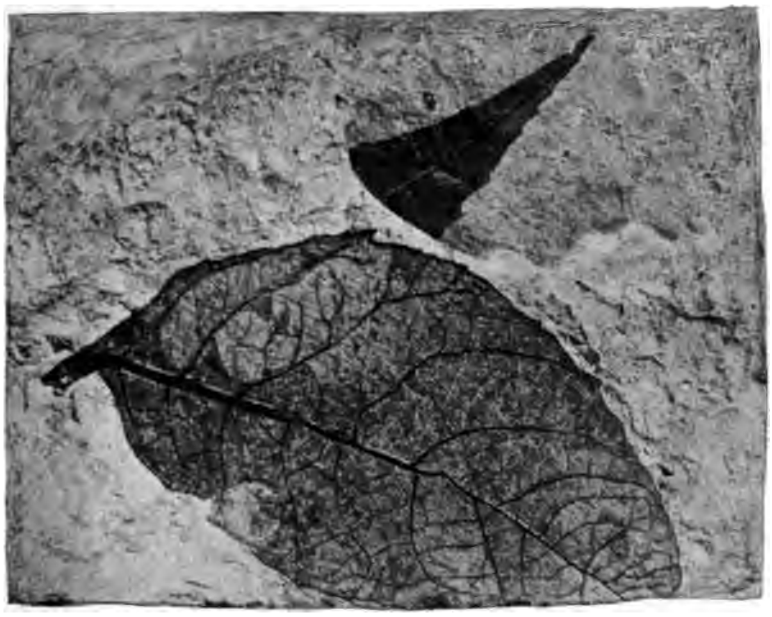

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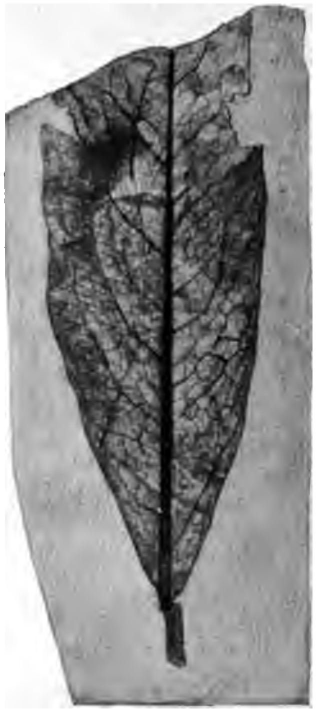

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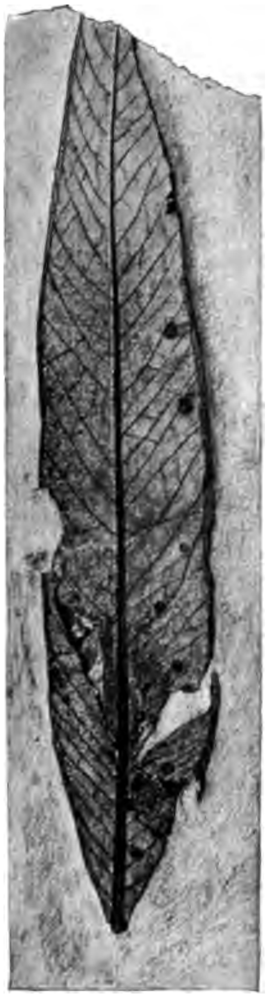
FLORA OF THE GREEN RIVER FORMATION.



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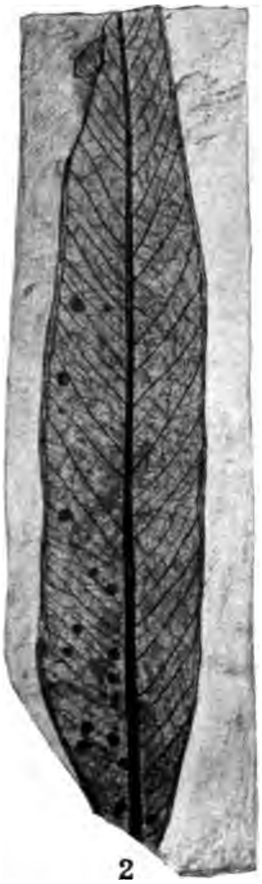

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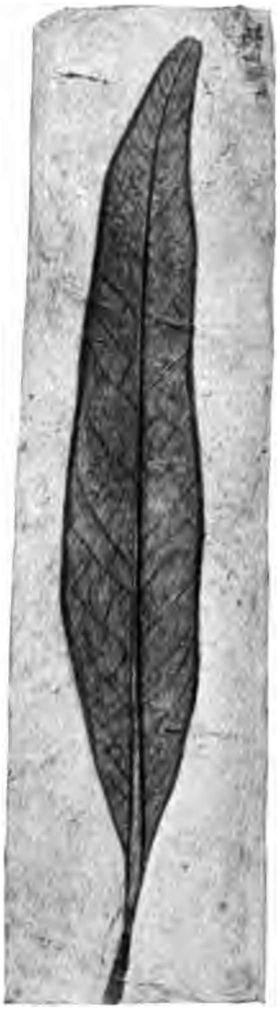

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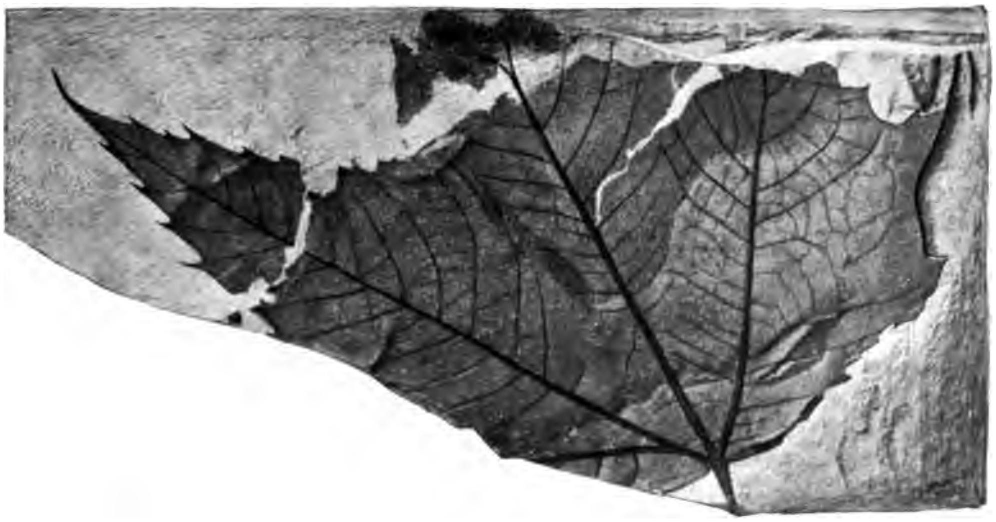

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FLORA OF THE GREEN RIVER FORMATION.

PLATE XXXIX.

FIGURES 1-3. *Eucalyptus? americanus* Lesquereux. Figures 1 and 2 from Little Duck Creek, 50 miles southwest of Meeker, Colo.; figure 3 from ridge between Carr and Bushy creeks, Garfield County, Colo. U. S. Nat. Mus. Nos. 36585, 36586, 36587. (See p. 171.)

4. *Aralia wyomingensis* Knowlton and Cockerell. From Cathedral Bluff, about 20 miles west of Rio Blanco post office, Colo. U. S. Nat. Mus. No. 36588. (See p. 172.)

PLATE XL.

FIGURES 1-3. *Mimosites coloradensis* Knowlton. From Little Duck Creek, about 50 miles southwest of Meeker, Colo. U. S. Nat. Mus. Nos. 36591, 36592, 36593. (See p. 166.)

4. *Achaenites cichorioides* Knowlton. From Camp Gulch, about 25 miles northwest of De Beque, Colo. U. S. Nat. Mus. No. 36594. (See p. 173.)

5, 6. *Dalbergia retusa* Knowlton. From Little Duck Creek, about 50 miles southwest of Meeker, Colo. U. S. Nat. Mus. Nos. 36595, 36596. (See p. 165.)

7. *Zizyphus longifolia* Newberry. From Greasewood Creek, about 40 miles southwest of Meeker, Colo. U. S. Nat. Mus. No. 36597. (See p. 169.)

8, 9. *Sambucus? winchesteri* Knowlton. Figure 8, natural appearance, × 6; figure 9, restoration of figure 8, × 9 From Rio Blanco County, Colo., about 40 miles southwest of Meeker. U. S. Nat. Mus. No. 36598. (See p. 173.)

10. *Dalbergia viridiflumensis* Knowlton. From Rio Blanco County, Colo., about 20 miles west of Rio Blanco post office. U. S. Nat. Mus. No. 36599. (See p. 164.)

11. *Sophora coloradensis* Knowlton. From Little Duck Creek, about 50 miles southwest of Meeker, Colo. U. S. Nat. Mus. No. 36600. (See p. 165.)

12. *Aralia wyomingensis* Knowlton and Cockerell. From Cathedral Bluff, about 20 miles west of Rio Blanco post office, Colo. U. S. Nat. Mus. No. 36601. (See p. 172.)

13. *Myrica* sp. From head of Carr Creek, about 30 miles northwest of De Beque, Colo. U. S. Nat. Mus. No. 36602. (See p. 158.)

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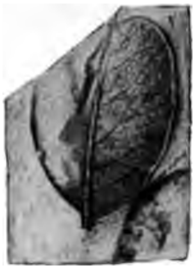
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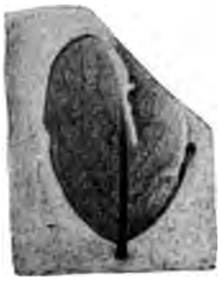
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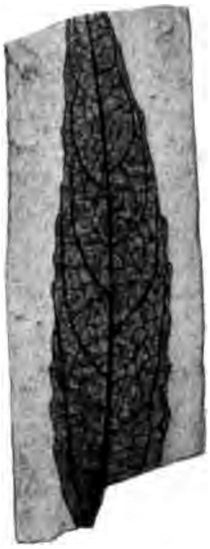
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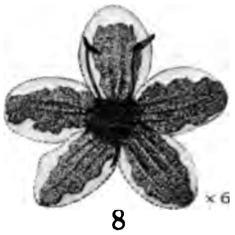

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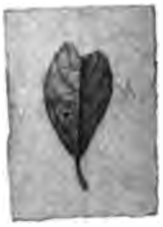
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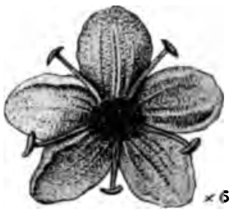

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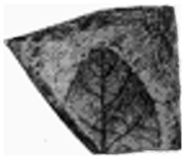
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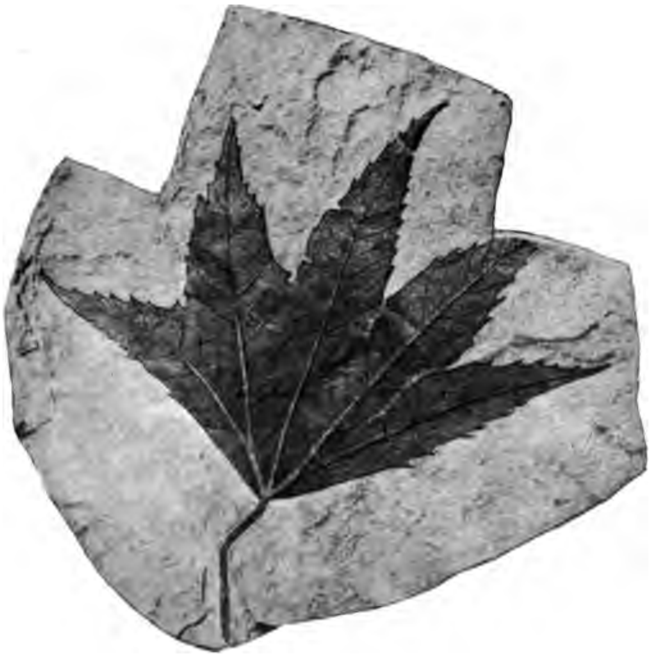
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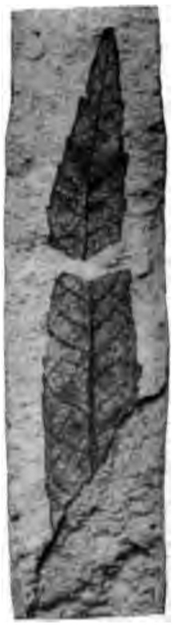
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FLORA OF THE GREEN RIVER FORMATION.

FOSSIL PLANTS FROM THE TERTIARY LAKE BEDS OF SOUTH-CENTRAL COLORADO.

By F. H. Knowlton.

The first of the Tertiary lake beds of Colorado to be brought to scientific attention were those at Florissant, discovered in 1873 by Dr. A. C. Peale, of the Hayden Geological Survey. Lake Florissant was a small lake, approximately 5 miles in length and not much if any exceeding a mile in width, occupying a mountain valley with its laterals eroded in granite by stream action. The present altitude of the lake beds is a little more than 5,000 feet above sea level. The composition of these beds is described by Henderson[1] as follows:

> The beds are composed chiefly of volcanic ashes, mud, and sand, the component particles of which are generally somewhat though not very much worn by the action of water. The conclusion reached in both field and laboratory is that the deposits were formed largely by volcanic ashes from repeated eruptions falling upon the surface of the water and settling to the bottom, assorted by the sluggish lake currents; also by mud and ashes falling or flowing into position where they were rapidly washed into the lake by rains, streams, and waves without much grinding.

The Florissant lake beds have proved to be highly fossiliferous, perhaps more abundantly so than any other deposits in the world. They are especially rich in remains of plants and insects. During the period of nearly 50 years since their discovery these fossil riches have been abundantly exploited, and they are now known to include more than 1,000 species of insects and nearly 250 species of plants.

The Florissant lake beds were long supposed to be unique, but the more and more intensive geologic work prosecuted in the Rocky Mountain region, especially within the last 20 years, has disclosed a number of other lake-bed deposits in the San Juan Mountain region of south-central Colorado. The object of the present paper is to bring to scientific attention the location, present known extent, and flora of these scattered lake beds. The description of the flora is purely preliminary and will undoubtedly be greatly increased with more thorough exploration.

The plants described in the following pages were all collected from rocks deposited during the volcanic period of the San Juan Mountain region, though from several different formations. The lake beds aggregate some thousands of feet in thickness, and there is evidence to show that several of the formational units were separated by periods of extensive erosion, during which canyons were cut to the depth of several thousand feet. The position in the geologic column can be understood from the accompanying generalized section, which has been supplied by E. S. Larsen, of the United States Geological Survey.

Mr. Larsen makes the following statement:

> The periods of erosion separating these formations were all of sufficient length to develop canyons several thousand feet deep and a youthful topography comparable to that of the present San Juan Mountains. This no doubt represents a very great number of years but only a small fraction of the time required to develop a mature topography.
>
> The most abundant and best-preserved plant remains were collected from the Creede formation. This formation is made up chiefly of thin-bedded rhyolite tuff in its lower part, but it carries much gravel, and some lava flows in its upper part. Some travertine is present. The formation was deposited in a deep, steep-walled basin that was cut in rocks of the Potosi volcanic series and that coincides approximately with the present valley of the Rio Grande from Wagon Wheel Gap westward to the mouth of Trout Creek, a distance of about 25 miles, but was considerably narrower. The maximum thickness is over 2,000 feet. The best plant remains were collected from the thinly laminated tuffs in the lower part of the formation. The cliffs exposed above Sevenmile Bridge are about 100 feet high and are almost continuous on the northwest bank of the river for over a mile.

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[1] Henderson, Junius, Colorado Univ. Studies, vol. 3, pp. 145-151, 1906.

The localities and the species found at each are listed below.

Cross. No. La G. 2 [5951]. Crude formation, La Garita quadrangle, Colo. Ridge north of stream which passes Hot Spring Hotel at altitude of 9,000 feet:

Minute fragments of bark, coniferous leaves, etc., but nothing determinable.

Cross. No. La G. 24 [5952]. Creede formation, south bank of Rio Grande 150 yards above wagon bridge, 3½ miles below Creede, Colo.:

Feather of bird.
Planera myricaefolia (Lesquereux) Cockerell.
Fragments.

Cross. No. La G. 93 [5953]. Creede formation, west side of Rio Grande one-fourth mile north of Sevenmile Bridge, below Creede, Colo., near boundary of San Cristobal quadrangle:

Pinus crossii Knowlton, n. sp.
Abies rigida Knowlton, n. sp.
Myrica myricaefolia (Lesquereux) Cockerell.
Feather of bird.

Cross. No. S. C. 1566 [5954]. Huerto formation, in a lens 100 yards long, N. 37½° E. of houses at north end of Lake Santa Maria, San Cristobal quadrangle, Colo., altitude 10,350 feet:

Pinus similis Knowlton, n. sp.
Ribes protomelaenum Cockerell.
Planera myricaefolia (Lesquereux) Cockerell?
Phyllites potentilloides Knowlton, n. sp.

Cross. 1911. No. La G. 536 [6198]. Creede formation, west side of Rio Grande near Sevenmile Bridge, near Creede, Colo., altitude 8,800–9,000 feet:

Pinus crossii Knowlton, n. sp.
Abies rigida Knowlton, n. sp.
Planera myricaefolia (Lesquereux) Cockerell.
Odostemon marginata (Lesquereux) Knowlton, n. comb.
Vitis florissantella Cockerell.
Populus lesquereuxi Cockerell.
Insect (beetle?).
Feathers.

Cross. 1914. No. 516 [6889]. Conejos (?) formation, Saguache quadrangle, Colo., gulch west of Henderson Mountain, about 1¼ miles north of Saguache River:

Coniferous wood, not further studied.

Cross. 1914. No. 437 [6858]. Saguache quadrangle, Colo., rhyolite tuff in railroad cut below (west of) Marshall Pass, where railroad crosses gulch at Shavano siding; geologic position uncertain but probably considerably below Conejos formation:

Pinus crossii Knowlton, n. sp.?
Fragments not determinable.

Larsen. 1916. [7242]. Creede formation, north bank of Rio Grande near Sevenmile Bridge, above Creede, Colo.:

Pinus crossii Knowlton, n. sp.
Pinus similis Knowlton, n. sp.
Pinus coloradensis Knowlton, n. sp.
Pinus florissanti? Lesquereux.
Abies rigida Knowlton, n. sp.
Sabina linguaefolia (Lesquereux) Cockerell.
Alnus? larseni Knowlton, n. sp.
Populus lesquereuxi Cockerell.
Planera myricaefolia (Lesquereux) Cockerell.
Ribes protomelaenum Cockerell.
Rubus? inquirendus Knowlton, n. sp.
Vitis florissantella Cockerell.
Odostemon marginata (Lesquereux) Knowlton, n. comb.
Odostemon hakeaefolia (Lesquereux) Knowlton, n. comb.
Sterculia aceroides Knowlton, n. sp.
Phyllites, two sp.

From the foregoing lists it appears that 5 of the 8 collections and no less than 18 of the 19 forms enumerated come from the Creede formation. From beds believed to belong to the Huerto formation the single collection yielded three named species, all of which occur also in the Creede formation.

A complete list of forms described in this paper is as follows:

Pinus crossii Knowlton, n. sp.
Pinus similis Knowlton, n. sp.
Pinus florissanti? Lesquereux.
Pinus coloradensis Knowlton, n. sp.
Abies rigida Knowlton, n. sp.
Abies longirostris Knowlton, n. sp.
Sabina linguaefolia (Lesquereux) Cockerell.
Populus lesquereuxi Cockerell.
Alnus? larseni Knowlton, n. sp.
Planera myricaefolia (Lesquereux) Cockerell.
Ribes protomelaenum Cockerell.
Rubus? inquirendus Knowlton n. sp.
Vitis florissantella Cockerell.
Odostemon marginata (Lesquereux) Knowlton, n. comb.
Odostemon hakeaefolia (Lesquereux) Knowlton, n. comb.
Sterculia aceroides Knowlton, n. sp.
Phyllites potentilloides Knowlton, n. sp.
Phyllites, two sp.

On eliminating the forms not named there remain 8 species described as new and 8 previously known species. As all these previously known species are found in the lake beds at Florissant, Colo., it seems reasonable to conclude that the age of the lake beds of the Creede formation is the same as that of the Florissant beds, namely, upper Miocene. From the Huerto formation were obtained three named species (*Pinus similis*, *Planera myricaefolia*, and *Ribes protomelaenum*) and an unamed *Phyllites*. All three of the named species are found in the Creede formation, and two of them are well-known Florissant species. The only other collection—that from Marshall Pass—contains a single doubtfully identified form (*Pinus crossii?*) and detached

leaves of *Pinus* and probably *Abies*. This collection is supposed to be much older than the others, but its position is somewhat uncertain.

So far as present known facts go it appears that the same flora ranges through the entire thickness of these lake deposits. Although the formational units involved are hundreds of feet thick, and although many of these units are separated by unconformities representing periods of erosion during which thousands of feet of beds were cut out, the deposition of the whole series occupied relatively so short a time that the changes in conditions do not appear to be reflected in the flora. Of course subsequent studies and collections may modify this conclusion, but it is all that can be said at present.

The flora of these lake beds as described in this paper is so small that it is perhaps hardly worth while to attempt any extensive discussion of the affinity, probable origin, and climatic requirements of the species included, yet they show a number of biologic features of considerable interest. The most abundant element in the flora consists of the Coniferae, which comprise over a third of the species and nearly half of the individual specimens. Although nine forms of conifers have been reported from the Florissant lake beds, all but one or two are very rare as individuals. It is probable that the increased elevation of the Creede deposits may account for the abundance of conifers, though more extended exploration will doubtless reduce this apparent preponderance. The most interesting of these conifers are the species of *Abies*, of which the specimens collected represent leafy branches and cone scales. It is possible that the branches and scales may belong to a single species, but as they are wholly unconnected it has been necessary to give them separate names. The cone scales indicate the group of *Abies* in which the bracts adhere firmly to the scale and are prolonged above into a long, slender tip, which may be as much as 4 centimeters in length. This group seems to be most closely related to *Abies venusta* Koch, the so-called silver fir of California. This is the first time, at least in this country, that cone scales of this type have been observed. The pines represent both the soft or white pines and the hard pines, the former known by their cluster of leaves in fives or fours.

The next in abundance and interest are the two species of *Odostemon*, the genus to which the well-known Oregon grape belongs. Both species—if they are really distinct—occur also in the Florissant beds, and it is believed that they are correctly placed generically, as they agree in all essential particulars with the living species. Four living species of *Odostemon* are now found in the Rocky Mountain area, and it would seem that they are the direct descendants of the Miocene forms.

None of the other genera (*Populus*, *Alnus*, *Ribes*, *Vitis*) offer features of particular biologic interest. The species referred with some question to *Rubus* is a small spray of flowers and immature fruit that if not actually a member of this genus is certainly very strongly suggestive of it.

The climatic requirements of this little flora would seem to be temperate, perhaps cool temperate, but it is still too small to warrant a very positive conclusion.

Pinus crossii Knowlton, n. sp.

Plate XLI, figures 3, 8–10.

Leaves in clusters of five, stout, rigid, slightly incurved, sharp pointed, 2.5 to about 4 centimeters long; sheaths of the leaf clusters deciduous.

This species is represented by a number of specimens, several of the best of which are figured. It is assumed that the normal number of leaves is five in each cluster, but there are a few examples in which only three can be made out. Thus, in the fragment of a branch shown in figure 3, there are two clusters, each with three leaves that otherwise agree with the five-leaved clusters. Although it is not impossible for the leaves to vary in number from three to five in the same species, it seems improbable in the present case, and, as stated above, the normal number is presumed to be five.

This species seems clearly to belong to the group of soft or white pines, not only as shown by the leaves being in clusters of five but more particularly by the complete absence of the sheath to the leaf bases. It seems to be most closely related to *Pinus albicaulis* Engelmann, a species of alpine slopes and exposed ridges throughout the Rocky Mountain region, at altitudes ranging from 5,000 to 12,000 feet.

Two species based on leaves have been described from the lake beds at Florissant—*Pinus hambachi* Kirchner,[2] supposed to have the leaves in clusters of three, and *Pinus wheeleri* Cockerell,[3] with the leaves in fives. In the original description of *P. wheeleri* the leaves are said to be 12 centimeters or more in length, but in descriptions of later specimens the length has been given as somewhat less. Nothing is said as to the sheath in this species, so this feature can not be compared with *P. crossii.*

Occurrence: Creede formation, north bank of Rio Grande near Sevenmile Bridge, Creede, Colo.; rhyolite tuff of unknown age but probably considerably older than Conejos formation, below (west of) Marshall Pass, Saguache quadrangle, Colo.

Pinus similis Knowlton, n. sp.

Plate XLI, figures 11, 12.

Leaves in clusters of four, stout, straight, 4.5 to 5.5 centimeters long; sheath of the leaf clusters absent.

It is with considerable hesitation that this form is described as a new species, as it may be only a slightly larger form of *Pinus crossii.* The base of the leaves is indistinguishable in appearance in the two forms, and the presence of only four leaves in the cluster of *P. similis* may be due to accident, though there is no evidence of it in the best preserved example. A single detached leaf on the same piece of matrix is the largest one observed (5.5 centimeters).

Individual leaves of this form are indistinguishable from leaves of *Pinus hambachi* Kirchner,[4] from the Florissant lake beds, but that species is said to have the leaves in clusters of three, and the resemblance may be only superficial.

Occurrence: Creede formation, north bank of Rio Grande, near Sevenmile Bridge, Creede, Colo.; Huerto formation, north end of Lake Santa Maria, San Cristobal quadrangle, Colo.

Pinus florissanti? Lesquereux.

Plate XLI, figure 7.

Pinus florissanti Lesquereux, U. S. Geol. Survey Terr. Rept., vol. 8 (Cretaceous and Tertiary floras), p. 138, pl. 21, fig. 13, 1883.

The collection contains a single large fragmentary cone that seems to be the same as *Pinus florissanti* Lesquereux.

Occurrence: Creede formation, north bank of Rio Grande, near Sevenmile Bridge, Creede, Colo.

Pinus coloradensis Knowlton, n. sp.

Plate XLI, figure 6.

Cone with a very short, thick stalk, ovoid, very obtuse at apex, 3 centimeters long, 2.3 centimeters in diameter; scales much thickened at the end; apparently with a short spine.

The example figured is the only one of this type observed in the collections. It is fairly perfect except for a few scales at the base. By making an impression in clay the original appearance is restored, as shown in figure 6. At first it was presumed that this specimen was probably the cone of *Pinus crossii,* with which it was associated, but whereas the absence of persistent sheaths to the leaf clusters proves that form to belong to the soft pines, the thickened tips of the scales in the present form show it clearly to belong to the hard pines. This form is, for instance, not greatly unlike the cone of *Pinus arizonica* Engelmann, but this resemblance is doubtfully to be interpreted as a real relationship.

The only fossil species of the region and age with which this may be compared is *Pinus florissanti* Lesquereux,[5] from the Florissant lake beds, but this is a cone 10 centimeters or more in length and 6 centimeters in diameter, and, moreover, the thickened tips of the cone scales appear to be different.

Occurrence: Creede formation, north bank of Rio Grande, near Sevenmile Bridge, Creede, Colo.

Abies rigida Knowlton, n. sp.

Plate XLI, figures 1, 2, 4, 5.

The collection from Creede contains a number of leafy branches that appear to belong to the genus *Abies,* but whether they represent

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[2] Kirchner, W. C. G., St. Louis Acad. Sci. Trans., vol. 9, p. 179, pl. 13, fig. 3, 1898.

[3] Cockerell, T. D. A., Am. Mus. Nat. Hist. Bull., vol. 24, p. 78, pl. 6, figs. 5, 11, 1908.

[4] Kirchner, W. C. G., St. Louis Acad. Sci. Trans., vol. 9, p. 174, pl. 13, fig. 3, 1898.

[5] Lesquereux, Leo, U. S. Geol. Survey Terr. Rept., vol. 8 (Cretaceous and Tertiary floras), pl. 21, fig. 13, 1883.

more than one species is difficult to decide. The one shown in figure 5 is a segment from a branch and is about 6 centimeters long, 6 millimeters in diameter at the base, and 5 millimeters at the apex. It shows the scars of leaves disposed in oblique rows. On one side the leaves are attached, these being apparently rather rigid, slightly arched upward, and obtusely pointed at the tips; they are about 12 millimeters long. The branch shown in figure 2 is the tip of a branch about 4 millimeters in diameter and has the leaves preserved on all sides. The leaves are much the same as in figure 5. Leaf scars are present at several points on the branch. Figure 4 is also the tip of a branch that retains most of the leaves. The leaves seem narrower and less rigid than in the other specimens mentioned; they are 2 centimeters or more in length. The specimen given in figure 1 is a shoot segment from which most of the leaves have fallen and is figured mainly because it shows the leaf scars so plainly. The leaves appear to agree most closely with those of figure 2.

It is possible that the specimens shown in figures 1 and 2 are specifically distinct from those of figures 4 and 5, but as only one type of *Abies* cone has been found it seems best to keep them together for the present. It is of course not at all certain that the cone scales belong to either of the branches, though it is perhaps a fair inference that they do.

Occurrence: Creede formation, north bank of Rio Grande, near Sevenmile Bridge, Creede, Colo.

Abies longirostris Knowlton, n. sp.

Plate XLII, figures 1, 2.

Cone scales thin, flat, much broader than long (16 to 18 millimeters wide, 8 to 10 millimeters long exclusive of the basal attached point); bracts of cone scales oblong, firmly attached to the scales and deciduous with them, prolonged above into a slender, rigid tip 2 to 4 centimeters long.

The collection contains a number of detached cone scales that appear certainly to belong to *Abies*. They are excellently preserved, the two selected for figuring being practically perfect. They show both sides of the scale. The one in figure 1 shows the back of the scale with the narrowly oblong bract firmly adhering to it and prolonged above into a rigid tip or spine fully 4 centimeters long. The other (fig. 2) exhibits the upper side of the cone scale with the bract prolonged above it for more than 4 centimeters.

This species appears to be most closely related to *Abies venusta* Koch, the so-called silver fir of the Santa Lucia Mountains in Monterey County, Calif.; at least it agrees with that species in some important particulars, such as the firm consolidation of the bract with the cone scale and its prolongation into the long, slender tip.

Occurrence: Creede formation, north bank of Rio Grande near Sevenmile Bridge, Creede, Colo.

Sabina linguaefolia (Lesquereux) Cockerell.

Sabina linguaefolia (Lesquereux) Cockerell, Colorado Univ. Studies, vol. 3, p. 175, 1906; Am. Mus. Nat. Hist. Bull., vol. 24, p. 79, 1908.

Knowlton, U. S. Nat. Mus. Proc., vol. 51, p. 249, 1916.

Widdringtonia linguaefolia Lesquereux, U. S. Geol. Survey Terr. Rept., vol. 8 (Cretaceous and Tertiary floras), p. 139, pl. 21, figs. 14, 14a, 1883.

This characteristic species is represented by a single branch with two or three short branchlets.

Occurrence: Creede formation, north bank of Rio Grande near Sevenmile Bridge, Creede, Colo.

Populus lesquereuxi Cockerell.

Plate XLIV.

Populus lesquereuxi Cockerell, Torrey Bot. Club Bull., vol. 33, p. 307, 1906.

Populus heerii Saporta. Lesquereux, U. S. Geol. Survey Terr. Rept., vol. 8 (Cretaceous and Tertiary floras), p. 157, pl. 30, figs. 1–8; pl. 31, fig. 11, 1883.

The basal portion with its petiole complete of a very large leaf is all that was found of this species. The petiole is nearly 3 millimeters thick and 7.5 centimeters long. The width of the blade is slightly more than 6 centimeters.

This leaf is similar in size to the largest one figured by Lesquereux (op. cit., pl. 30, fig. 5), which lacks the basal portion and the petiole, which the present leaf supplies. Lesquereux's leaf must have been nearly or quite 24 centimeters in length.

Occurrence: Creede formation, west bank of Rio Grande near Sevenmile Bridge, Creede, Colo.

Alnus? larseni Knowlton, n. sp.

Plate XLII, figure 3.

Leaf small, evidently firm in texture, elliptical, about equally narrowed to both base and apex; margin sharply serrate; petiole long, slender; nervation faintly preserved, consisting of a relatively strong midrib and seven or eight pairs of thin secondaries at an angle of about 40°; finer nervation not retained.

Only a single specimen of this form with its counterpart was found in the collection. It is regularly elliptical, 6 centimeters long and 2.8 centimeters wide, with the petiole preserved for a length of 1.5 centimeters.

I am a little in doubt as to the generic reference of this leaf. In living species of *Alnus* the margin is often doubly serrate, sometimes crenate-dentate, and only rarely—as, for instance, in *Alnus maritima* Nuttall—simply serrate. The present leaf is similar to *Alnus corrallina* Lesquereux,[a] from the Miocene of California, but it has fewer, more irregular secondaries. The finer nervation can not be compared.

The species is named in honor of Esper S. Larsen, of the United States Geological Survey, who collected it.

Occurrence: Creede formation, north bank of Rio Grande near Sevenmile Bridge, Creede, Colo.

Planera myricaefolia (Lesquereux) Cockerell.

Plate XLIII, figures 16, 17.

Planera myricaefolia (Lesquereux) Cockerell, Am. Mus. Nat. Hist. Bull., vol. 24, p. 88, 1908.

Knowlton, U. S. Nat. Mus. Proc., vol. 51, p. 266, pl. 21, fig. 2, 1916.

Planera longifolia myricaefolia Lesquereux, U. S. Geol. Survey Terr. Rept., vol. 8 (Cretaceous and Tertiary floras), p. 161, pl. 19, figs. 14-27, 1883.

The collection from Creede contains about a dozen leaves that are undoubtedly identical with this species. They are smaller than the average leaves figured by Lesquereux, though not smaller than the smallest one.

Occurrence: Creede formation, north bank of Rio Grande near Sevenmile Bridge, Creede, Colo. Huerto formation, north end of Lake Santa Maria, San Cristobal quadrangle, Colo.

Rubus? inquirendus Knowlton, n. sp.

Plate XLIII, figure 11.

Inflorescence racemose, main axis zigzag, about 14 millimeters long, flowers scattered, pediceled, the pedicels slender, 2 or 3 millimeters long; calyx inferior, five-parted; fruit (?) obscure.

It is with some hesitation that this little inflorescence is referred to *Rubus*. It is very small and delicate, and the preservation is not all that could be desired. Neither the main axis nor the pedicels are provided with prickles or glands, nor is each pedicel subtended by a bract, as in many living species; but, on the other hand, there are a number of recent species without all or some of these features. The calyx is very obscure. It appears certainly to be inferior and five-parted, though only three lobes are preserved in any one flower. The central part of the "flower" is so poorly preserved that its exact nature can not be made out with certainty. It may consist of a definite number or possibly a mass of carpels.

It is possibly unwise to attempt even a tentative placing of this fragment, but fossil flowers and fruits are so rare that even poorly preserved specimens may have some value. This form is perhaps definite enough to permit its recognition if again found.

Occurrence: Creede formation, north bank of Rio Grande near Sevenmile Bridge, Creede, Colo.

Ribes protomelaenum Cockerell.

Plate XLII, figures 5–9.

Ribes protomelaenum Cockerell, Am. Mus. Nat. Hist. Bull., vol. 24, p. 93, pl. 7, fig. 15, 1908.

This species was founded on a single example from the Florissant lake beds and is described as being about 4.6 centimeters long and fully 6 centimeters broad. It is described as having the base deeply cordate, "the sides of the basal portion rounded, without lobes." The figure shows that the basal portion is entirely absent on one side, and the other appears rather indefinite.

The collection from Creede contains about a dozen leaves referred to this species, of various sizes and very perfectly preserved. They are all distinctly five-lobed, and the basal lobes are smaller than the upper lobes and in some specimens nearly entire. The largest leaf (fig. 8) is 5.3 centimeters long to the top of the petiole and 5.7 centimeters broad. It has the petiole preserved for a length of 1 centimeter. The next in size (fig. 9) is absolutely perfect and is 3 centimeters long and 4 centimeters broad between the upper lobes. The petiole complete is 1.8 centimeters long. Still smaller leaves are shown in figures 5-7. Figure 7 represents an almost perfect leaf 1.7 centimeters long and 2.3 centimeters wide, with the petiole 1.2 centimeters long.

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[a] Lesquereux, Leo, U. S. Geol. Survey Terr. Rept., vol. 8 (Cretaceous and Tertiary floras), pl. 51, figs. 1–3, 1883.

Ribes protomelaenum resembles closely a number of living species. Cockerell compared it to *Ribes nigrum* Linné and *R. hudsonianum* Richards, but even more clearly it seems to me to resemble *R. rubrum* Linné and *R. prostratum* L'Héritier.

Occurrence: Creede formation, north bank of Rio Grande near Sevenmile Bridge, Creede, Colo.; Huerto formation, north end of Lake Santa Maria, San Cristobal quadrangle, Colo.

Vitis florissantella Cockerell.

Plate XLII, figure 4.

Vitis florissantella Cockerell, Am. Mus. Nat. Hist. Bull., vol. 24, p. 102, pl. 7, fig. 18, 1908.

A single leaf with its counterpart clearly belongs to this species. It is even smaller than the type, being only about 22 millimeters long and 23 millimeters broad. It lacks the basal portion but otherwise agrees with the type.

Occurrence: Creede formation, west bank of Rio Grande near Sevenmile Bridge, Creede, Colo.

Odostemon marginata(?) (Lesquereux) Knowlton, n. comb.

Plate XLIII, figures 7-10.

Hedera marginata Lesquereux, U. S. Geol. Survey Terr. Rept., vol. 8 (Cretaceous and Tertiary floras), p. 177, pl. 40, fig. 8, 1883.

Leaves pinnate (?), at least trifoliolate, petiole short, stout; leaflets coriaceous in texture, closely sessile at the top of the petiole, nearly circular or broadly ovate, very obtusely wedge-shaped, truncate or even slightly heart-shaped at base, the margin with usually three strong teeth or lobes on each side, the lobes sharp-pointed and apparently spine-tipped; nervation palmate from the base, the middle rib slightly stronger, other nervation much joined or sometimes running to the lateral lobes.

The specimens from Creede that are here figured have been the basis of a good deal of study and not a little speculation. It was early recognized that they were certainly identical with the *Hedera marginata* of Lesquereux, but the question of their relationship was much in doubt. It seemed improbable that they were correctly referred to *Hedera;* in fact, Lesquereux expressed the opinion when the species was first described that he knew "nothing to which this leaf may be related," and others have expressed the same uncertainty. It was not until the specimen with the leaflets attached was discovered that the affinity of this form was suspected. This specimen (fig. 7) has one leaflet complete and the bases of the other two, together with the perfect petiole. The best leaflet is 10 millimeters long and 7 or 8 millimeters broad. The spread of the whole leaf should be about 22 millimeters; the length of the petiole is 8 millimeters. The best preserved leaflet has three teeth on the lower side and two on the upper side. The terminal leaflet has only the obtusely wedge-shaped basal portion preserved.

Another well-preserved leaflet is the one shown in figure 9. It is slightly larger than the one just described, being about 18 millimeters long and 17 millimeters wide. It has large spine-tipped teeth and in size, teeth, and nervation closely resembles the type of *Hedera marginata.* Still larger, but so fragmentary that it can not be accurately measured, is the one seen in figure 10. This has the nervation well preserved and also the spine on one of the teeth. The largest specimen—figure 8—is nearly perfect. It is oblique and slightly heart-shaped at the base and has the usual strong teeth and the characteristic nervation. Its length is about 28 millimeters and its width about 30 millimeters.

The genus *Odostemon* Rafinesque (*Mahonia* of Nuttall; *Berberis* section *Mahonia* of authors) comprises about 20 species in central Asia, China, North America, and adjacent Mexico. They are unarmed shrubs with pinnately compound spinose-toothed evergreen leaves.

Occurrence: Creede formation, north bank of Rio Grande, near Sevenmile Bridge, Creede, Colo.

Odostemon hakeaefolia (Lesquereux) Knowlton, n. comb.

Plate XLIII, figures 1-6.

Lomatia hakeaefolia Lesquereux, U. S. Geol. Survey Terr. Rept., vol. 8 (Cretaceous and Tertiary floras), p. 166, pl. 32, fig. 19, 1883.

Lomatites haekaefolia (Lesquereux) Cockerell, Am. Mus. Nat. Hist. Bull., vol. 24, p. 89, 1908.

Knowlton, U. S. Nat. Mus. Proc., vol. 51, p. 267, pl. 26, figs. 1, 2, 1916.

Carduus florissantensis Cockerell, Torrey Bot. Club Bull., vol. 33, p. 311, text fig. 6, 1906.

?*Odostemon florissantensis* Cockerell, Am. Mus. Nat. Hist. Bull., vol. 24, p. 91, 1908.

The leaves of *Odostemon* are pinnate, and it is assumed that the leaves of the present fossil species were similarly arranged, but as none have thus far been found attached it is impossible to be certain. The leaflets, if this has been correctly interpreted, were closely sessile, with an obtusely wedge-shaped or nearly truncate base and slender, sharp-pointed apex. They are lanceolate in general outline, with usually three teeth on each side; these teeth are separated by rounded sinuses and are spinous tipped, as is the apical lobe. The nervation consists of a relatively strong midrib and a rather loose network of veins that supply the several lobes. The leaflets are evidently thick and coriaceous in texture and have the margin all around thickened as if bound with a cord, precisely as in the living species. The length varies between 2 and 4 centimeters and the width between 1 and 2 centimeters. Some of the specimens, perhaps the majority, are broadest at the base, and others are broadest between the points of the upper lobes.

If my assumption is correct, as it is now believed to be, this species was first described under the name *Lomatia hakeaefolia* Lesquereux[7] from material collected in the Florissant lake beds. It was based on a single specimen about 5 centimeters long and 2.5 centimeters wide. It has four teeth or lobes on each side and no trace of nervation except a strong midrib.

Lesquereux states that his *Lomatia hakeaefolia* he regards as closely related to his *Lomatia spinosa*, which was described[8] at the same time. *L. spinosa* was also based on a single specimen about 8 centimeters long and 2.5 centimeters wide and differs from *L. hakeaefolia* in being deeply cut into very large, sharp-pointed lobes. The apical portion especially is drawn out into a long, slender point. There is no nervation preserved except a short basal portion of the midrib.

These two species are certainly congeneric and probably conspecific. Additional examples of Lesquereux's *Lomatia hakeaefolia* have been procured at Florissant by Cockerell, Knowlton, and others. The leaves figured in my recent paper[9] on the Florissant plants are undoubtedly identical with *L. hakeaefolia;* and *L. spinosa* of Lesquereux is only an elongated, narrow, stronger-toothed form. It is comparable, for instance, to the specimen shown in figure 1 except as regards size, the latter being only about half as long.

The leaf described by Cockerell[10] as *Carduus florissantensis* undoubtedly belongs here, being indistinguishable from figure 1. The thickened margin and peculiar arched veins more or less parallel to the midrib he describes are characters of *Odostemon.*

Cockerell[11] also described as *Odostemon florissantensis* a leaflet from Florissant that probably belongs with *Odostemon hakeaefolia.* It was not figured but is said to be similar to *Odostemon simplex* (Newberry) Cockerell (*Berberis simplex* Newberry), from the upper Eocene of Bridge Creek, Oreg., except that the "inferior basal angle is produced into a tooth, so that the truncate base of the leaf is greatly broadened." It is about 4.2 centimeters long and 4.8 centimeters wide and has three teeth on each side, "not counting the base." This seems to fit the description of *Odostemon hakeaefolia*, and therefore Cockerell's form has been referred to that species.

Occurrence: Creede formation, north bank of Rio Grande near Sevenmile Bridge, Creede, Colo.

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[7] Lesquereux, Leo, U. S. Geol. Survey Terr. Rept., vol. 8 (Cretaceous and Tertiary floras), p. 166, pl. 32, fig. 19, 1883.

[8] Lesquereux, Leo, op. cit., p. 166, pl. 43, fig. 1.

[9] Knowlton, F. H., U. S. Nat. Mus. Proc., vol. 51, p. 267, pl. 26, figs. 1, 2, 1916.

[10] Cockerell, T. D. A., Torrey Bot. Club Bull., vol. 33, p. 311, text fig. 6, 1906.

[11] Cockerell, T. D. A., Am. Mus. Nat. Hist. Bull., vol. 24, p. 91, 1908.

Sterculia aceroides Knowlton, n. sp.

Plate XLIII, figure 12.

Leaf small, semicoriaceous in texture, rounded and truncate at the base, three-lobed, the central lobe apparently much the longest and strongest (broken), lateral lobes short, acute, at an angle of about 45°; nervation obscure, except for the very strong midrib and the much lighter lateral ribs. which arise near the base of the blade.

This little leaf, the only one seen in the collection, has the basal portion well preserved, but the evidently large central lobe is broken. The distance between the tips of the lateral lobes is about 3.5 centimeters.

Two species of *Sterculia* have been described from material found in the Florissant lake beds—*Sterculia rigida* Lesquereux[12] and *S. engleri* Kirchner.[13] These species are of the same type, about the only difference being in size; they should probably be combined.

The present form differs from the Florissant forms in being rounded and full instead of wedge-shaped at the base and in having relatively shorter lateral lobes. The central lobe, to judge from the very strong midrib, was probably very long and slender. The nervation, except for the three ribs, is practically obsolete.

Occurrence: Creede formation, north bank of Rio Grande. near Sevenmile Bridge, Creede, Colo.

Phyllites sp.

Plate XLIII, figure 15.

Leaf minute, delicate in texture, obovate, rounded at the apex, long ridge-shaped at the base; apparently short petioled; margin entire; nervation very delicate, consisting of a straight midrib and about three pairs of thin secondaries that pass up for a considerable distance; finer nervation obsolete.

This little leaf or leaflet, the only one observed in the collection, is about 7 millimeters long and 5 millimeters broad. It was apparently sessile, or nearly so.

I have hesitated to assign this leaf to a definite genus, as it is so nondescript that it is hard to place with any degree of reasonableness. It resembles a number of described forms, such as *Celastrus murchisoni* Heer,[14] from the Swiss Miocene, though it is much smaller. It is also similar to certain leaflets that have been called *Leguminosites*, but conjectures as to its affinity would hardly serve any useful end.

Occurrence: Creede formation, north bank of Rio Grande near Sevenmile Bridge, Creede Colo.

Phyllites sp.

Plate XLIII, figure 13.

In the collections from Creede I find the little leaf here figured, which with its counterpart is the only one noted. It is small, about 18 millimeters long and 9 millimeters broad, ovate, somewhat decurrent at the base, and moderately pointed at the apex. The margin has about four relatively large, sharp-pointed teeth on each side. The nervation is very light, consisting of a straight midrib and four pairs of thin, opposite secondaries, which end in the teeth.

It is so difficult, not to say impossible, to place this little leaf in the correct genus that it has been referred without specific name to the nondescript genus *Phyllites*.

Occurrence: Creede formation, north bank of Rio Grande near Sevenmile Bridge, Creede, Colo.

Phyllites potentilloides Knowlton, n. sp.

Plate XLIII, figure 14.

The material from Lake Santa Maria includes the single example figured, which appears to be a small compound leaf with at least seven leaflets. The terminal leaflet is deeply cut into three lanceolate segments, the margins of which are provided with rather remote, sharp teeth. The lower leaflets are sessile or nearly so, lanceolate-acuminate, with sharply toothed margins. The nervation consists of a very strong midrib and a few secondaries that seem to enter the teeth. The whole leaf is about 5 centimeters long, and the lower leaflets are 1.5 to 2 centimeters long and 0.5 centimeter wide.

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[12] Lesquereux, Leo, U. S. Geol. Survey Terr. Rept., vol. 8 (Cretaceous and Tertiary floras), p. 179, pl. 34, fig. 12, 1883.

[13] Kirchner, W. C. G., St. Louis Acad. Sci. Trans., vol. 8, p. 180, pl. 14, fig. 3, 1898.

[14] Heer, Oswald, Flora tertiaria Helvetiae, vol. 3, pl. 121, fig. 6, 1859.

This specimen is so well preserved that seemingly it should not be difficult to place generically, but nevertheless its generic reference is uncertain. It resembles a number of things, particularly certain pinnate-leaved species of *Potentilla*, such as *P. hippiana* Lehmann, but there are features that do not agree, and rather than make a wrong generic reference I think best to place it, at least temporarily, in *Phyllites*. It has been given a specific name that suggests its resemblance to *Potentilla*.

Occurrence: Huerto formation, north end of Lake Santa Maria, San Cristobal quadrangle, Colo.

PLATES XLI—XLIV.

PLATE XLI.

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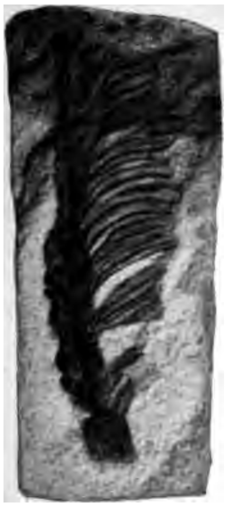
FIGURES 1, 2, 4, 5. *Abies rigida* Knowlton, from Creede formation, near Creede, Colo. U. S. Nat. **Mus. catalog** Nos. 36505, 36507, 36508, 36509 186

6. *Pinus coloradensis* Knowlton, from Creede formation, near Creede, Colo. U. S. Nat **Mus.** catalog No. 36506 186

7. *Pinus florissantii?* Lesquereux, from Creede formation, near Creede, Colo. U. S. Nat. **Mus.** catalog No. 36510 186

3, 8-10. *Pinus crossii* Knowlton, from Creede formation, near Creede, Colo. U. S. Nat. **Mus. catalog** Nos. 36511, 36512, 36513, 36514 185

11, 12. *Pinus similis* Knowlton, from Creede formation, near Creede, Colo. U. S. Nat. **Mus. catalog** Nos. 36515, 36516 186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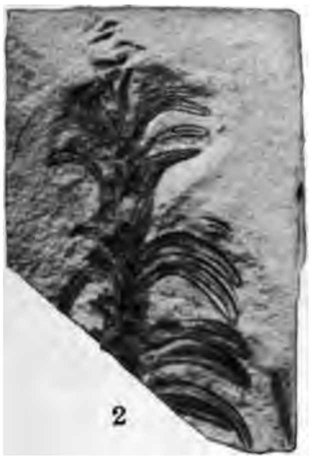
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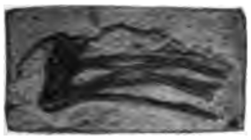
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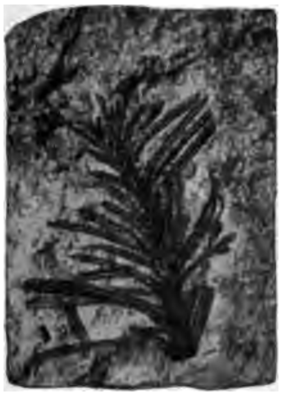
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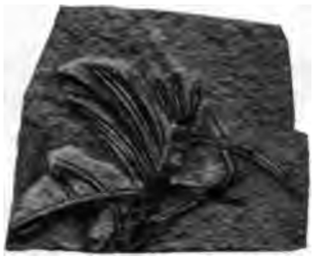
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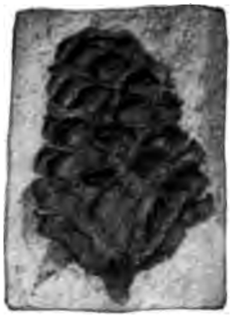
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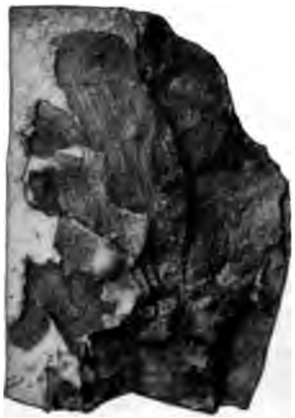
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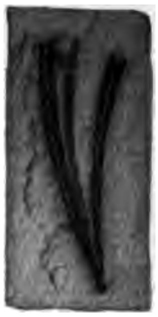
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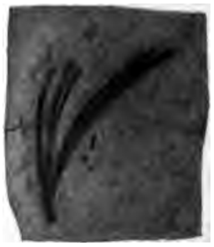
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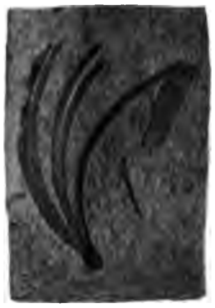
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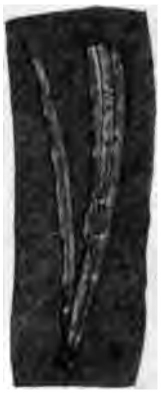
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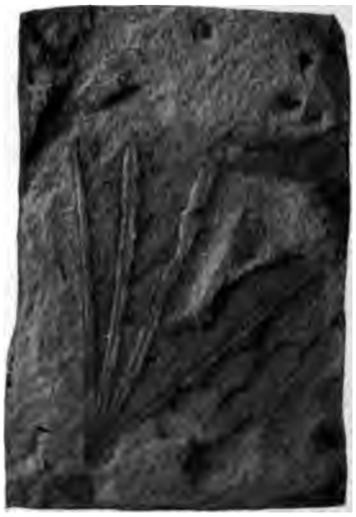
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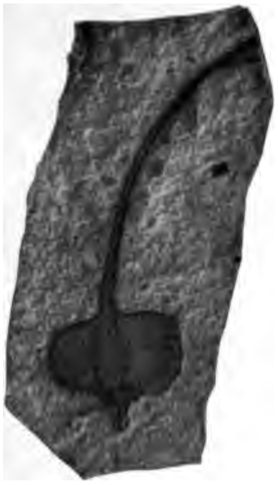
FOSSIL PLANTS FROM THE TERTIARY LAKE BEDS OF SOUTH-CENTRAL COLORADO.



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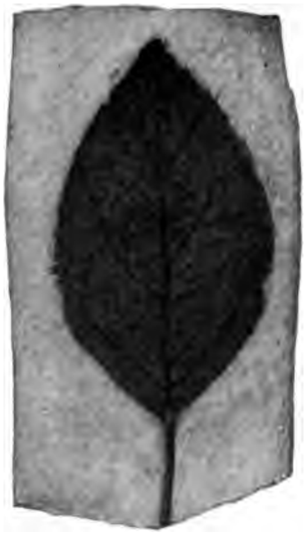

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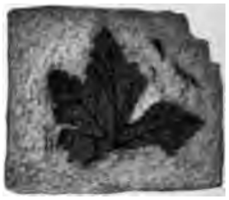

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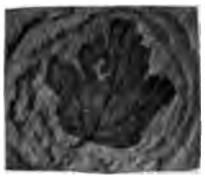

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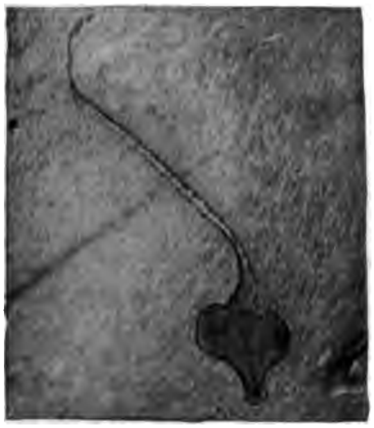

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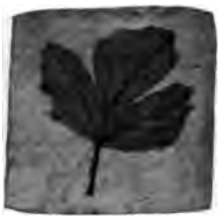

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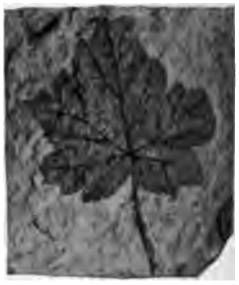

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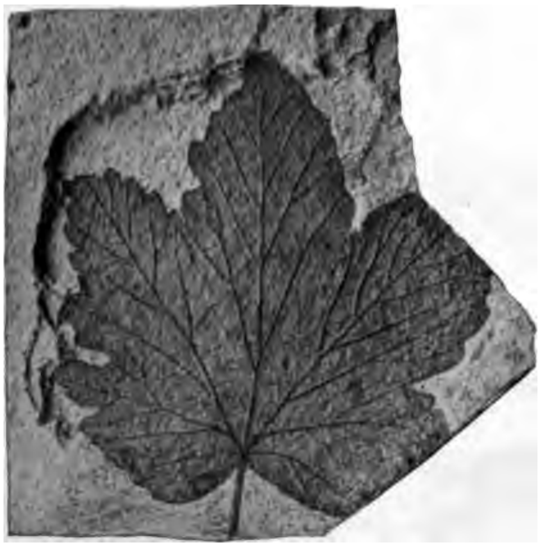

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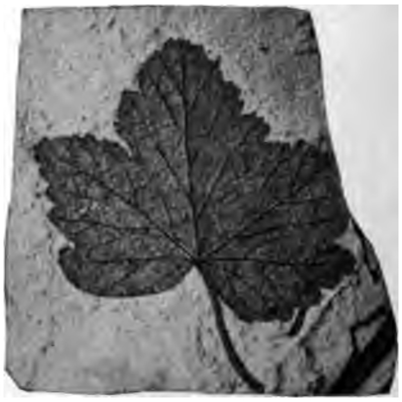

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FOSSIL PLANTS FROM THE TERTIARY LAKE BEDS OF SOUTH-CENTRAL COLORADO.

PLATE XLII.

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3.	*Alnus? larseni* Knowlton, from Creede formation, near Creede, Colo. U. S. Nat. Mus. catalog No. 36519	188
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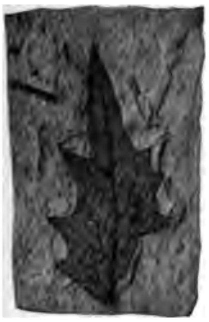
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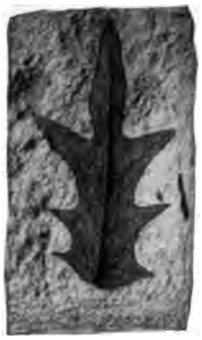
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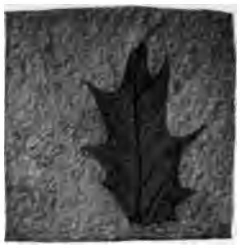
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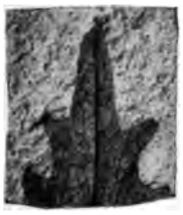
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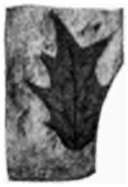
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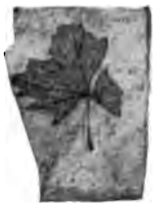
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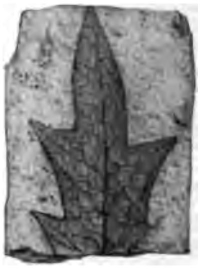
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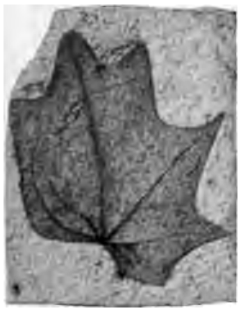
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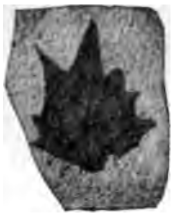
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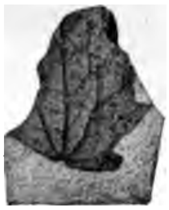
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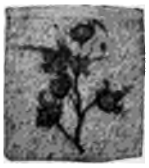
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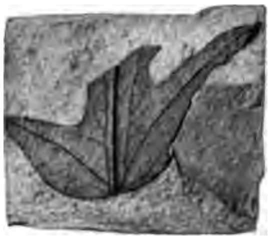
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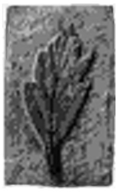
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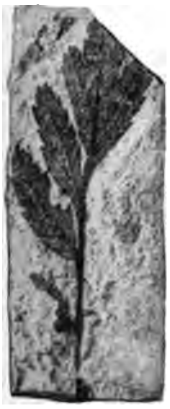
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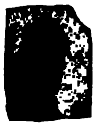
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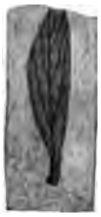
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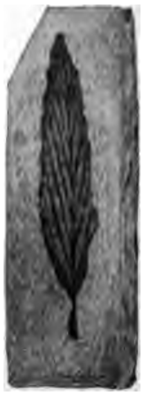
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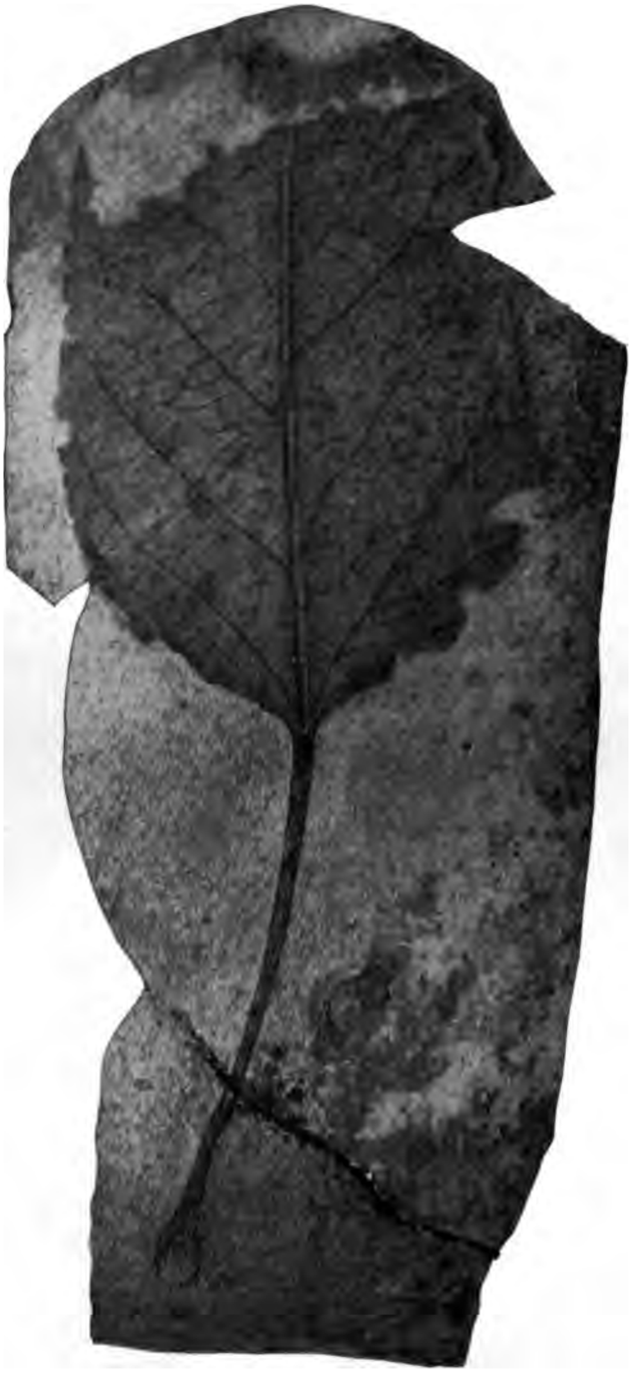
FOSSIL PLANTS FROM THE TERTIARY LAKE BEDS OF SOUTH-CENTRAL COLORADO.



FOSSIL PLANT FROM THE TERTIARY LAKE BEDS OF SOUTH-CENTRAL COLORADO.

PLATE XLIV.

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Populus lesquereuxi Cockerell, from Creede formation, near Creede, Colo. U. S. Nat. Mus. catalog No. 36543....	187

THE FAUNA OF THE SO-CALLED DAKOTA FORMATION OF NORTHERN CENTRAL COLORADO AND ITS EQUIVALENT IN SOUTHEASTERN WYOMING.

By John B. Reeside, Jr.

INTRODUCTION.

This paper describes a small fauna from beds in northern central Colorado that have long been designated the Dakota formation, often with doubt that all the beds so named were really equivalent to the typical Dakota sandstone of eastern Nebraska. The upper part of the equivalent beds in southeastern Wyoming was referred by some writers to the Benton shale and the lower part to the Cloverly formation. This so-called Dakota formation of northern central Colorado and its equivalent in southeastern Wyoming consist of cherty conglomerate, brown quartzose sandstone, and dark shale. The conglomerate is usually at the base of the series and at many localities is overlain by a single shale unit and that in turn by a sandstone. At other localities, however, there are several alternations of sandstone and shale above the basal conglomeratic layer. The fossils described in this paper, except one specimen, were obtained from the shales of the middle part of the formation. The single specimen, an ammonite, came from the uppermost sandstone.

Fossils from the "Dakota formation" of northern Colorado were first recorded by Prof. Junius Henderson,[1] of the University of Colorado. Henderson states that fossils were found by T. W. Stanton and himself at almost every good exposure of the "medial shales" from a locality 5 miles north of Boulder, Colo., to Owl Canyon, in northern Larimer County, though they were not determinative. He suggests that the presence of Comanche fossils at Canon City and the persistence of a tripartite division in the "Dakota formation" indicate "that at least part of the medial shales and lower sandstone member in the Boulder district and northward may be the time equivalent of the Comanche." The fossils of the northern area are mostly in poor condition and are said to include one or more species of *Ostrea*, an *Inoceramus* indistinguishable from *I. labiatus* Schlotheim, and an *Avicula* closely related to *A. linguaeformis* Evans and Shumard, though probably not identical.

Mr. Stanton made six collections from as many localities in 1906 and others in 1909 and 1920. In 1907 Prof. Henderson made a collection of which a part was presented by him to the Geological Survey. In 1921 larger collections were made at six localities by W. T. Lee. These later collections have supplied more adequate specimens of most of the species than were contained in the earlier collections and have shown more definitely the relationships of the fossils. All the material in these collections has, through Mr. Stanton's kindness, been in the writer's hands, as well as specimens for comparison from the Washita fauna of southern Colorado, New Mexico, Kansas, and Texas contained in the collections of the Geological Survey.

THE FAUNA AND ITS RELATIONS.

The fauna of the "middle Dakota shale" of northern Colorado and southern Wyoming includes seven species, of which one is not definitely determinable, three are assigned to new species, and three are assigned to species previously described. The list of species is as follows:

Inoceramus comancheanus Cragin.
Inoceramus bellvuensis Reeside, n. sp.
Pteria salinensis White.
Ostrea larimerensis Reeside, n. sp.
Ostrea noctuensis Reeside, n. sp.
Anchura kiowana Cragin?
Ammonite, undetermined.

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[1] Henderson, Junius, The foothills formations of north-central Colorado: Colorado Geol. Survey First Ann. Rept., pp. 172-176, 1908; The Cretaceous formations of northeastern Colorado and the foothills formations of north-central Colorado: Colorado Geol. Survey Bull. 19, pp. 83-85, 1920.

To this list may be added the scales and bones of undetermined fish and also teeth collected near Loveland, Colo., by Prof. Henderson and identified by J. W. Gidley as probably plesiosaurian.[2] *Inoceramus comancheanus*, *Pteria salinensis*, and *Anchura kiowana* occur in rocks of Washita age in Kansas and other States, and their occurrence in the beds here considered therefore supports a correlation of the "middle Dakota" with the Washita group, although such a correlation, based on a single species each of *Inoceramus* and *Pteria* and a somewhat doubtfully identified species of *Anchura*, has a rather frail foundation. The other species are not very close to any described forms from the Washita group or the Benton shale and have little value in correlation. The absence of such widespread and abundant species as *Ostrea quadriplicata* Shumard, *Gryphaea corrugata* Say, *Trigonia emoryi* Conrad, *Pholadomya sanctisabae* Roemer, *Cardium kansasense* Meek, *Protocardia multilineata* Shumard, *Turritella seriatim-granulata* Roemer, and *Pachydiscus brazoensis* (Shumard), which occur in many collections from the Purgatoire formation and its equivalents,[3] is surprising. There is no feature of the sediments that indicates conditions of deposition in northern Colorado very different from those in southern Colorado—in fact, on the contrary, the sediments of the two areas are so much alike that tentative correlations between them have been based on the similarity. It is difficult to explain why conditions that would permit the existence of *Inoceramus comancheanus*, *Pteria salinensis*, and an *Anchura* very like *A. kiowana* would completely shut out any trace of their usual associates, which are present in southern Colorado, scarcely 200 miles away. Whether these three species were hardier and could endure conditions that completely precluded the existence of the other species can not be determined. The Washita fauna, as shown by Stanton,[4] suffers a progressive change northwestward from the Tucumcari region of New Mexico and the Cimarron River region of Oklahoma by the disappearance of one species after another from the faunal assemblage. In the Purgatoire River region of Colorado the fauna lacks a number of Washita species that are prominent at the localities farther southeast. In the Apishapa River region still more species have dropped out of the fauna, and at Canon City only two or three are known. Such a change as this may well account for the paucity of recognized Washita species in northern central Colorado and southeastern Wyoming, though the causes of the change are entirely conjectural. It has been suggested by Stanton[5] that the difference between the fauna of the Purgatoire formation and that of the so-called Dakota formation of northeastern Colorado is due to a difference in age, the sea in which the Purgatoire formation was deposited not having reached northern Colorado until Dakota time, when many of the characteristic Washita species had ceased to exist. The relationship of the beds of Washita age in Kansas to the overlying Dakota formation is so intimate as to preclude any great difference in age, and the difference in interpretation of the fauna is therefore not very great. However, it seems to the writer that it is better to regard the fossils of the so-called Dakota formation as of the same age as those of the Purgatoire formation and attribute the differences between them to some now unknown difference in the conditions under which the sediments were deposited. The fauna from northern Colorado, in spite of its paucity, is more like that of the Washita group than that of the succeeding Benton shale or that of any known Dakota beds, and a correlation based on the fauna must be a correlation with the Washita rather than with the Benton. The fauna is apparently an extension of the known range of the late Comanche fauna as far north as southern Wyoming.

The single ammonite, *Pachydiscus?* sp., from the uppermost sandstone of the "Dakota formation," is sufficient only to show that this sandstone is in at least one locality of marine origin. The specimen might belong to the Washita fauna or to a later one. The marine origin of the sandstone at two other localities is indicated by the presence of *Halymenites*. These localities are at the mouth of Little

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[2] Henderson, Junius, The Cretaceous formations of northeastern Colorado and the foothills formations of north-central Colorado: Colorado Geol. Survey Bull. 19, p. 85, 1920.

[3] Stanton, T. W., The Morrison formation and its relations with the Comanche series and the Dakota formation: Jour. Geology, vol. 13, pp. 657-669, 1905.

[4] Stanton, T. W., idem.

[5] Stanton, T. W., Some problems connected with the Dakota sandstone: Geol. Soc. America Bull., vol. 33, pp. 265-272, 1922.

Thompson Canyon and 10 miles north of Boulder, Boulder County, Colo.[6]

DISTRIBUTION OF SPECIES.

The following table and list show the geographic distribution of the species described in this paper:

Distribution of species from the so-called Dakota formation of northern central Colorado and southern Wyoming by localities.

	1[a]	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Inoceramus comancheanus Cragin	×	....	....	×	×	....	....	×	×	×	×	×	....	×	×	×
Inoceramus bellvuensis Reeside	....	....	....	×	....	....	....	....	×	×	×	....	....	....	....	....
Pteria salinensis White	×	×	×	×	....	×	....	×	....	×	×	×	....	....	×	×
Ostrea larimerensis Reeside	....	....	....	....	....	×	....	×	×	×	×	....	....	×	....	×
Ostrea noctuensis Reeside	....	....	....	×	....	×	×	×	×	×	×	....	....	....	....	....
Anchura kiowana Cragin?	....	....	....	....	....	....	....	×	....	×	×	....	....	....	....	....
Pachydiscus? sp	....	....	....	....	....	....	....	....	....	....	....	....	×	....	....	....
Ammonite, undetermined	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	×
Fish scales and bones	....	×	....	....	×	×	×	×	×	×	....	....	....	×	×	×

[a] Numbers refer to the localities given in the following list.

1. U. S. G. S. locality 3689. Sixmile Canyon, 4 miles north of Boulder, Boulder County, Colo.; sandy shale between the "Dakota" sandstones; T. W. Stanton, collector, 1906:

Inoceramus comancheanus Cragin.
Pteria salinensis White.
Ostrea sp. undetermined.

2. U. S. G. S. locality 3690. Lykins Gulch, 9 miles north of Boulder, Boulder County, Colo.; sandy shale between the "Dakota" sandstones; T. W. Stanton, collector, 1906:

Pteria salinensis White.
Ostrea sp. undetermined.
Fish remains.

3. U. S. G. S. locality 3685. South end of Rabbit Mountain, 7 miles northwest of Longmont, Boulder County, Colo.; shales between the "Dakota" sandstones; T. W. Stanton, collector, 1906:

Inoceramus sp. undetermined.
Pteria salinensis White.
Ostrea sp. undetermined.

4. U. S. G. S. locality 3686. Lykins ranch, at mouth of canyon of Little Thompson Creek, Boulder County, Colo.; sandy shale between the "Dakota" sandstones; T. W. Stanton, collector, 1906:

Inoceramus comancheanus Cragin.
Inoceramus bellvuensis Reeside.
Pteria salinensis White.
Ostrea noctuensis Reeside.

5. U. S. G. S. locality 10631. Handy ditch, canyon west of Loveland, Larimer County, Colo.; sandy shale beneath the "upper Dakota" sandstone; W. T. Lee, collector, 1921:

Inoceramus comancheanus Cragin.
Fish remains.

6. U. S. G. S. locality 10657. Handy ditch, canyon west of Loveland, Larimer County, Colo.; middle of shale between the "Dakota" sandstones: W. T. Lee, collector, 1921.

Inoceramus sp. undetermined.
Pteria salinensis White.
Ostrea larimerensis Reeside.
Ostrea noctuensis Reeside
Fish remains.

7. U. S. G. S. locality 3688. Eight miles northwest of Loveland and 2 miles north of the junction of Big Thompson and Buckhorn creeks, Larimer County, Colo.; sandy shale between the "Dakota" sandstones; T. W. Stanton, collector, 1906:

Ostrea noctuensis Reeside.
Fish remains.

8. U. S. G. S. locality 10659. Soldier Canyon, west of Fort Collins, Larimer County, Colo.; middle of shale of "middle Dakota"; W. T. Lee, collector, 1921:

Inoceramus comancheanus Cragin.
Pteria salinensis White.
Ostrea larimerensis Reeside.
Ostrea noctuensis Reeside.
Anchura kiowana Cragin?
Fish remains.

9. U. S. G. S. locality 3687. Ditch bank on north side of Cache la Poudre River, 9 miles northwest of Fort Collins and 2 miles above Laporte, Larimer County, Colo.; shale between the "Dakota" hogbacks; T. W. Stanton, collector, 1906.

Inoceramus comancheanus Cragin.
Inoceramus bellvuensis Reeside.
Ostrea larimerensis Reeside.
Ostrea noctuensis Reeside.
Fish remains.

10. U. S. G. S. locality 10660. Ditch on "Dakota" ridge in sec. 12, T. 8 N., R. 70 W., north of Bellvue, Larimer County, Colo.; upper part of "middle Dakota"; W. T. Lee, collector, 1921:

Inoceramus comancheanus Cragin.
Inoceramus bellvuensis Reeside.
Pteria salinensis White.
Ostrea larimerensis Reeside.
Ostrea noctuensis Reeside.
Anchura kiowana Cragin?
Fish remains.

11. U. S. G. S. locality 5401. Owl Canyon, 12 miles north of Fort Collins, Larimer County, Colo.; "middle Dakota"; Junius Henderson, collector, 1907·

Inoceramus comancheanus Cragin.
Inoceramus bellvuensis Reeside.
Pteria salinensis White.
Ostrea larimerensis Reeside.

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[6] Henderson, Junius, The Cretaceous formations of northeastern Colorado and the foothills formations of north-central Colorado: Colorado Geol. Survey Bull. 19, p. 85, 1920.

Ostrea noctuensis Reeside.
Anchura kiowana Cragin?

12. U. S. G. S. locality 10375. Two miles southeast of Greenacre ranch, 20 miles north of Fort Collins, Larimer County, Colo.; dark shale beneath the "upper Dakota" hogback; T. W. Stanton, collector, 1920:

Inoceramus comancheanus Cragin.
Pteria salinensis White.

13. U. S. G. S. locality 10375a. Same locality as 10375; upper sandstone of the "Dakota" hogback, above the dark shales; T. W. Stanton, collector, 1920:

Pachydiscus? sp.

14. U. S. G. S. locality 10662. Schoolhouse near Box Elder Creek, southeast of Greenacre ranch, Larimer County, Colo.; upper part of "middle Dakota"; W. T. Lee, collector, 1921:

Inoceramus comancheanus Cragin.
Ostrea larimerensis Reeside.
Fish bone.

15. U. S. G. S. locality 5863. Horse Creek, 30 miles northwest of Cheyenne, Laramie County, Wyo.; shale beneath the upper ledge of the "Dakota"; T. W. Stanton, collector, 1909:

Inoceramus comancheanus Cragin.
Pteria salinensis White.
Gastropod, undetermined.
Fish remains.

16. U. S. G. S. locality 10670. Gap of Chugwater Creek at Iron Mountain, Laramie County, Wyo.; "middle Dakota" shale; W. T. Lee, collector, 1921:

Inoceramus comancheanus Cragin.
Pteria salinensis White.
Ostrea larimerensis Reeside.
Ammonite, undetermined.
Fish remains.

DESCRIPTIONS OF SPECIES.

Genus INOCERAMUS Sowerby.

Inoceramus comancheanus Cragin.

Plate XLV, figures 1-7

1895. *Inoceramus comancheana* Cragin, Colorado Coll. Studies, 5th year, pp. 53-55.

1901. *Inoceramus comancheanus* Cragin. Hill, U. S. Geol. Survey Twenty-first Ann. Rept., pt. 7, pl. 35, fig. 4.

1920. *Inoceramus comancheanus* Cragin. Adkins and Winton, Texas Univ. Bull. 1945, p. 73, pl. 17, fig. 1-3.

Cragin's original description is as follows:

> Shell equivalve, broadly and obliquely rhombic-ovate, more gibbous than that of *I. labiatus* Schlotheim, the axis of greatest dimension diverging from the hinge line much more widely than in the latter species; alar outline rounded; anterior margin descending steeply in a nearly straight line for a considerable distance on front of the beaks, then curving rather suddenly away toward the somewhat prominently convex distal part of the basal outline, anterior and posterior margins making nearly a right angle with each other; beaks placed opposite the anterior extremity of the hinge, moderately inflated and moderately elevated above the hinge line, anteriorly flattened but not abruptly so; hinge plate rather short, broad, the ligamental grooves crowded, more numerous and longer than in *I. labiatus*, though ample and shallow; valves thin, ornamented with numerous concentric riblike folds, which on the distal and ventral parts are quite strongly elevated and much narrower than the intervals between them.
>
> Height 82, length 95, breadth 54, axis of greatest dimension 107 milimeters. In some examples the species attains considerably larger dimensions.

The writer has in hand a number of fairly good specimens of an *Inoceramus* indistinguishable from specimens of *I. comancheanus*. This species is characterized by its elongate form, the axis of elongation making an angle of 50° to 70° with the hinge line; moderately coarse, rounded, concentric ribs without finer sculpture between; ribs somewhat irregular; umbo rather slender; anterior margin straight or slightly concave, making an angle of 70° to 100° with the hinge line. It differs from the later *I. labiatus*, as pointed out by Cragin, in the greater angle between the axis of elongation and the hinge line. It is also less elongated, has stronger sculpture and less smoothly ovate concentric ribs, and lacks the fine striae between the concentric ribs. It somewhat resembles an undescribed species associated with *I. labiatus* and related to *I. lamarcki* var. *cuvieri* Sowerby, though it differs in having a more elongate form and much finer sculpture. *Inoceramus anglicus* Woods, of the Gault; *I. crippsi* Mantell, of the Cenomanian; and *I. pictus* Sowerby, of the Cenomanian, are related species. *I. anglicus* has more regular concentric ribs and a broader curvature and is a wider shell. *I. crippsi* has a greater angle between the anterior margin and the hinge line (140°), a thicker umbo, and fine striae between the concentric ribs. *I. pictus* differs chiefly in possessing finer sculpture. These comparisons are based largely on figures by Woods [7] and might not hold in an actual comparison of specimens, but so far as the writer is able to determine, *I. comancheanus* is closer to *I. crippsi* and *I. pictus* than to the other species mentioned.

Occurrence: Many localities in Texas, Kansas, Oklahoma, and southern Colorado. In northern Colorado: Sixmile Canyon, Lykins ranch, canyon west of Loveland, Soldier Canyon, Cache la Poudre River, north of

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[7] Woods, Henry, A monograph of the Cretaceous Lamellibranchia of England, vol. 2, pt. 7, pp. 264, 273, 279, text figs. 29, 33-36; pl. 45, figs. 8-10; pl. 48, figs. 2, 3; pl. 49, figs. 5, 6, 1911.

Bellvue, Owl Canyon, 2 miles southeast of Greenacre ranch, Boxelder Creek. In Wyoming: Horse Creek and Iron Mountain.[8]

Inoceramus bellvuensis Reeside, n. sp.

Plate XLVI, figures 1-3.

Shell apparently equivalve, very inequilateral. Outline of valve subquadrate; anterior part moderately convex; posterior part flattened, forming an ill-defined wing dorsally. Anterior margin nearly straight; ventral margin broadly convex; posterior margin nearly straight. Anterior margin makes an angle of 120° with the hinge line. Small part of hinge line preserved shows ligament pits small and shallow. Umbones nearly terminal. Ornamentation of somewhat irregular narrow concentric ribs with unsymmetrical curvature; interspaces wider than ribs, concave.

This species is marked by its broad subquadrate valves, small convexity, and sculpture. It is perhaps closer to *Inoceramus crippsi* Mantell than to any other species but shows no trace of the fine striae between the ribs that are present on that species.

The specific name is derived from Bellvue, Colo., near which the type was collected.

Occurrence: Lykins ranch, Cache la Poudre River, north of Bellvue, and Owl Canyon, Colo.

Genus PTERIA Scopoli.

Pteria salinensis White.

Plate XLVII, figures 1-5.

1880. *Pteria* (*Oxytoma*) *salinensis* White, U. S. Nat. Mus. Proc., vol. 2, pt. 2, pp. 296, 297, pl. 5, figs. 1, 2.

1883. *Pteria* (*Oxytoma*) *salinensis* White, U. S. Geol. and Geog. Survey Terr. Twelfth Ann. Rept., pt. 1, pp. 15, 16, pl. 16, figs. 2a, b.

?1893. *Pteria salinensis* White. Cragin, Texas Geol. Survey Fourth Ann. Rept., p. 211.

White's original description is as follows:

> Shell rather large for a Cretaceous *Pteria;* the body, exclusive of the wings, obliquely subovate, broad at the base, moderately gibbous, distinctly but not very greatly inequivalve; the left valve, as usual, more convex than the right and its beak more prominent; the convexity of the valves somewhat uniform but increasing toward the umbonal region in each, where it is greatest; anterior wing moderately large, defined from the body of the shell by being laterally compressed but not by any distinct auricular furrow, the byssal sinus under the anterior wing of the right valve having the usual size and shape common to *Oxytoma*; posterior wing not proportionately large and not distinctly defined from the body of the shell except by a somewhat gradual lateral compression; its posterior angle not greatly produced; hinge line less than the axial length of the shell; posterior adductor scars not distinct; anterior adductor scars distinct and deep for a shell of this genus, placed immediately in front of the beaks, that of the left valve being more distinct than the other. * * *
>
> It is known to have reached an axial length of more than 60 millimeters, a transverse width near its base of at least 50 millimeters, and a thickness of about 25 millimeters when both valves were in natural position.
>
> The character of the surface is not known, but it was evidently nearly smooth, as is usual with *Oxytoma*.

The writer has in hand a number of specimens that include both valves of a smooth-shelled *Pteria*. Such simple shells are somewhat unsatisfactory material for comparisons, as very similar species occur at a number of very distinct horizons, from the Paleozoic on. However, in comparison with species from the Washita, Colorado, and Montana groups the specimens in hand are so close to *P. salinensis* that it is difficult to pick out an essential difference. *P. gastrodes* (Meek) of the Benton is a large, stout, nearly equivalve shell with the outline of the valves well rounded, the anterior ear short proportionately, and the axis of the shell only moderately oblique. *P. linguaeformis* (Evans and Shumard) is a proportionately small, inequivalve shell, with valves rather elongated and oblique, and the anterior ear small. *P. salinensis* has a less elongated form than *P. linguaeformis* and is much larger, but it is not nearly so stout and rounded as *P. gastrodes*. It has also a relatively long and narrow anterior ear and is nearly equivalve.

Occurrence: Washita group of Texas and rocks of same age in Kansas and southern Colorado. In northern Colorado: Sixmile Canyon, Lykins Gulch, Lykins ranch, south end of Rabbit Mountain, canyon west of Loveland, Soldier Canyon, north of Bellvue, Owl Canyon, and 2 miles southeast of Greenacre ranch. In Wyoming: Horse Creek and Iron Mountain.

Genus OSTREA Linnaeus.

Ostrea larimerensis Reeside, n. sp.

Plate XLVII, figures 6-12.

Shell very thin, flattened, acutely triangular in outline; small, an average specimen attaining a length of 60 millimeters. Beak narrowly tapered; base of valve smoothly rounded.

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[8] The full description of all these localities is given on pages ——.

Margins of the valves smooth. Surface irregularly and finely wrinkled, especially near the beak. Internal cast reflects the larger wrinkles, but otherwise smooth. Hinge not seen; probably small and weakly developed.

The writer has hesitated to apply names to this and the following species of *Ostrea*. Both belong to a type of simple oyster that appears in many faunas from Jurassic to Recent time, and although differences may be pointed out the variability of the shells is so great that no differences seem to hold good, and separation into species is more or less arbitrary. However, there appear to be no described forms in the equivalent or adjacent faunas of the region that may be compared with these, and as a matter of convenience names are here applied.

The specific name of *O. larimerensis* is derived from Larimer County, Colo.

Occurrence: Canyon west of Loveland, Soldier Canyon, Cache la Poudre River, north of Bellvue, Owl Canyon, and Box Elder Creek, Colo.; Iron Mountain, Wyo.

Ostrea noctuensis Reeside, n. sp.

Plate XLVIII, figures 1–5.

Shell very thin, gently arched, subquadrate, of medium size, an average individual attaining a length of 80 or 90 millimeters. Beak bluntly rounded, basal part of shell broadly rounded. Margins of valves smooth. Surface of most of the specimens marked by fine, rather regular concentric lines and a few broad, obscure folds. Surface of other specimens irregularly wrinkled, much as in *O. larimerensis*. Internal cast smooth except for the reflection of the broad folds. Hinge small and weak.

This species may possibly be only a variant of *O. larimerensis*, as it is of the same general type, but its broad outline is distinct, and so is its sculpture in most of the specimens.

The specific name is derived from the locality of the type, Owl Canyon (*noctuus* = owl).

Occurrence: Lykins ranch, canyon west of Loveland, northwest of Loveland, Soldier Canyon, Cache la Poudre River, north of Bellvue, and Owl Canyon, Colo.

Genus ANCHURA Conrad.

Anchura kiowana Cragin?

Plate XLVIII, figures 6–8.

1895. *Anchura kiowana* Cragin, Colorado Coll. Studies, 5th year, pp. 66, 67.

Cragin's original description is as follows:

> Shell small, consisting of six convex whorls; spire elevated; suture impressed; wing of moderate size, consisting of a proximal flangelike part, continued posteriorly across half or more of the first spire whorl, and a carinated falciform process; carina gradually arising at the base of the falciform process and traversing the latter to the extremity; falciform process much shorter and less upturned distally than that of the somewhat similar species *A. ruida* White, not rising to the lowest level of the suture between the body whorl and the first spire whorl but having its point directed outward and somewhat upward so as to make a large angle with the axis of the spire, extero-inferior outline of wing rounded and the border between this and the canal sinuous, margin of upper (flange) part of wing describing a slightly concave to sigmoid outline and more or less thickened and reflexed; inner lip provided with a moderately broad and prominent callous; canal short and obliquely truncated; spire whorls and posterior half to two-thirds of body whorl ornamented with narrow curved, subvertical ribs or folds, of which there are about 24 on the first spire whorl, and with numerous revolving striae, the latter ornamentation gradually becoming prominent and superseding the ribs on the lowest third to half of the body whorl.
>
> Height 19, breadth of body whorl, including excursion of the wing, 15 millimeters; angle of spire slopes about as in *A. ruida* White. * * * This species is distinguished from *Anchura ruida* White by the vertically costate body whorl, by the shorter, differently directed falciform process, and by having the alar carina confined directly to the wing and nearly to the falciform process instead of being common to the wing and part of the body whorl.

The writer has six specimens of a small species of *Anchura*, all poorly preserved but showing enough of the details to indicate a close relationship to *A. kiowana*, as defined by Cragin's description and by good specimens. One specimen preserves a mold of the exterior of the wing, and although fine details are lacking it is clear that the wing has the form of that of *A. kiowana* and that the carina is confined practically to the wing. The presence of vertical ribs is also indicated on the body whorl of this specimen. Another specimen preserving a mold of the spire and perhaps part of the body whorl shows a strong sculpture like that on *A. kiowana*. The material available is inadequate for certain identification, but the differences from *A. ruida* White and other species of equivalent and adjacent formations and the resemblances to *A. kiowana* make a tentative assignment to that species justifiable

Occurrence: Kiowa shale of Kansas. Soldier Canyon, north of Bellvue, and Owl Canyon, Colo.

Genus PACHYDISCUS Zittel.

Pachydiscus? sp.

Plate XLIX, figure 1.

A single specimen of an ammonite, much weathered and preserving few details but suggesting strongly the genus *Pachydiscus*, is contained in the collections. It might well be a weathered specimen of *P. brazoensis* (Shumard), but it might equally well belong to some later species, and even a certain generic assignment must await better material.

The stratigraphic position of this specimen is a little higher than that of the remainder of the fossils described in this paper. It came from the upper sandstone of the "Dakota" hogback, above the dark shales, and not from the shales themselves, as did the other fossils.

Occurrence: Two miles southeast of Greenacre ranch, Colo.

Ammonite, genus and species undetermined.

Plate XLIX, figure 2.

A single small specimen of an ammonite preserving few distinctive features is contained in the collections. The shell is clearly that of a much compressed species with very small umbilicus and truncated but unchanneled venter. The earlier part of the shell preserved shows coarse, apparently rounded ribs, but the later part is practically smooth. The greatest diameter of the shell is 30 millimeters, and the width of the truncated venter a little more than 1 millimeter. The shell might be a species of *Engonoceras*, *Knemiceras*, *Metoicoceras*, or some other genus.

Occurrence: Iron Mountain, Wyo.

Fish scales and bones, undetermined.

Plate L, figures 1-11.

Fish scales and bones occur at several of the localities from which fossils are described in this paper. Some of them resemble *Leuchichthyops vagans* Cockerell,[9] and others resemble *Ichthyodectes* sp. Cockerell.[10] A few specimens are figured for the sake of more completely illustrating the known fauna.

Occurrence: Lykins Gulch, canyon west of Loveland, northwest of Loveland, Soldier Canyon, Cache la Poudre River, north of Bellvue, and Box Elder Creek, Colo.; Horse Creek and Iron Mountain, Wyo.

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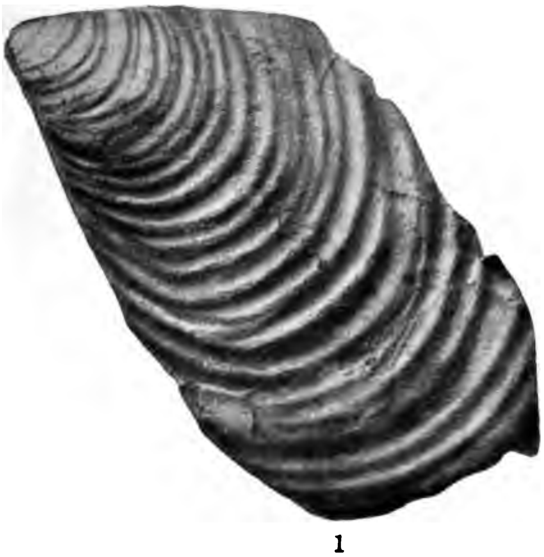
[9] Cockerell, T. D. A., Some American Cretaceous fish scales: U. S. Geol. Survey Prof. Paper 120, p. 180, pl. 35, figs. 1-15, 1919.

[10] Idem, p. 179, pl. 34, figs, 3, 4.

PLATES XLV-L.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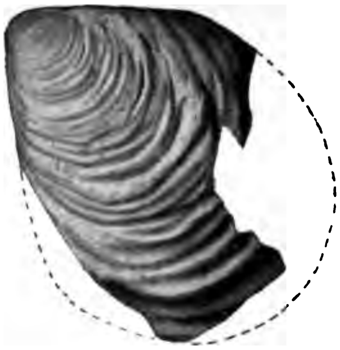
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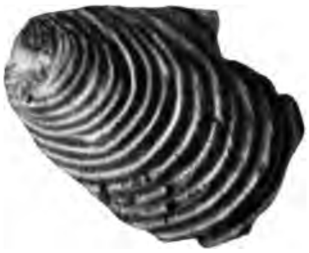
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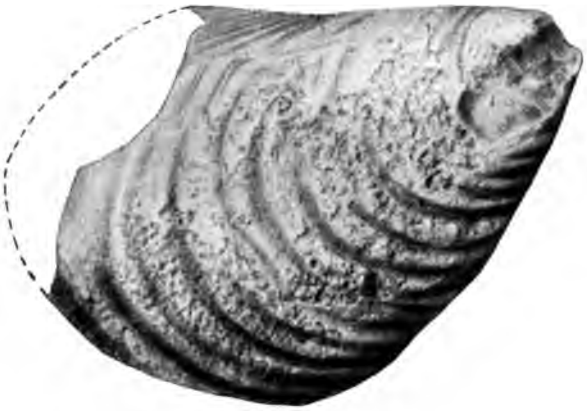
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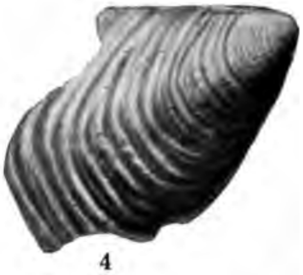
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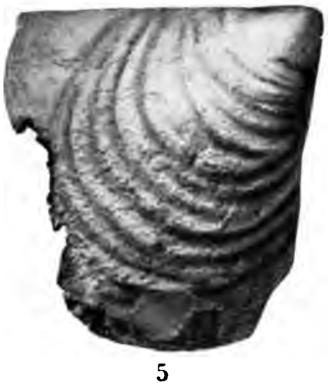
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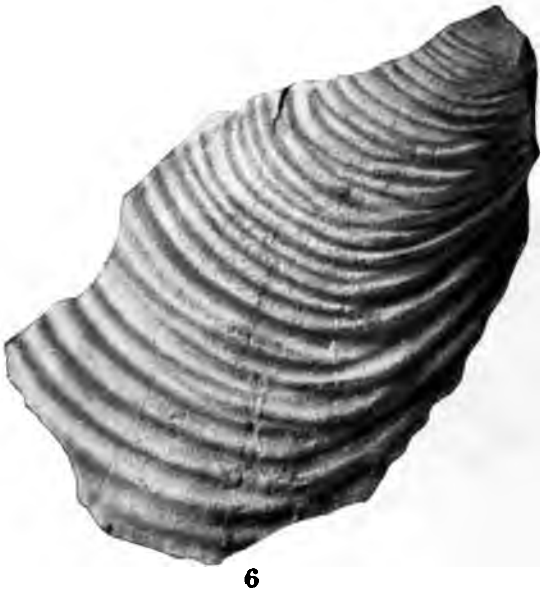
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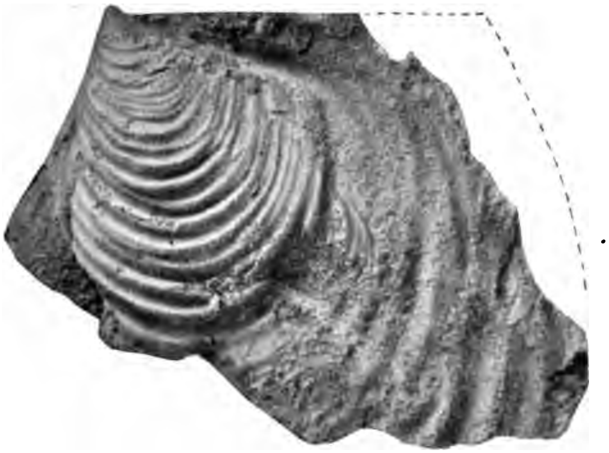
FOSSILS OF THE SO-CALLED DAKOTA FORMATION OF NORTHERN CENTRAL COLORADO AND SOUTHEASTERN WYOMING.

Inoceramus comancheanus Cragin, north of Bellvue, Colo. 1-3, Left valves of three specimens (U. S. Nat. Mus. catalog No. 32513); 4-7. right valves of four specimens (U. S. Nat. Mus. catalog No. 32513).



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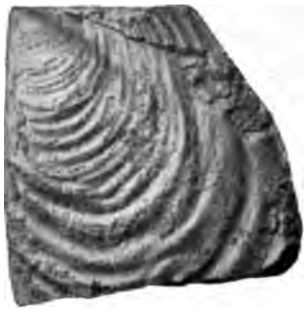

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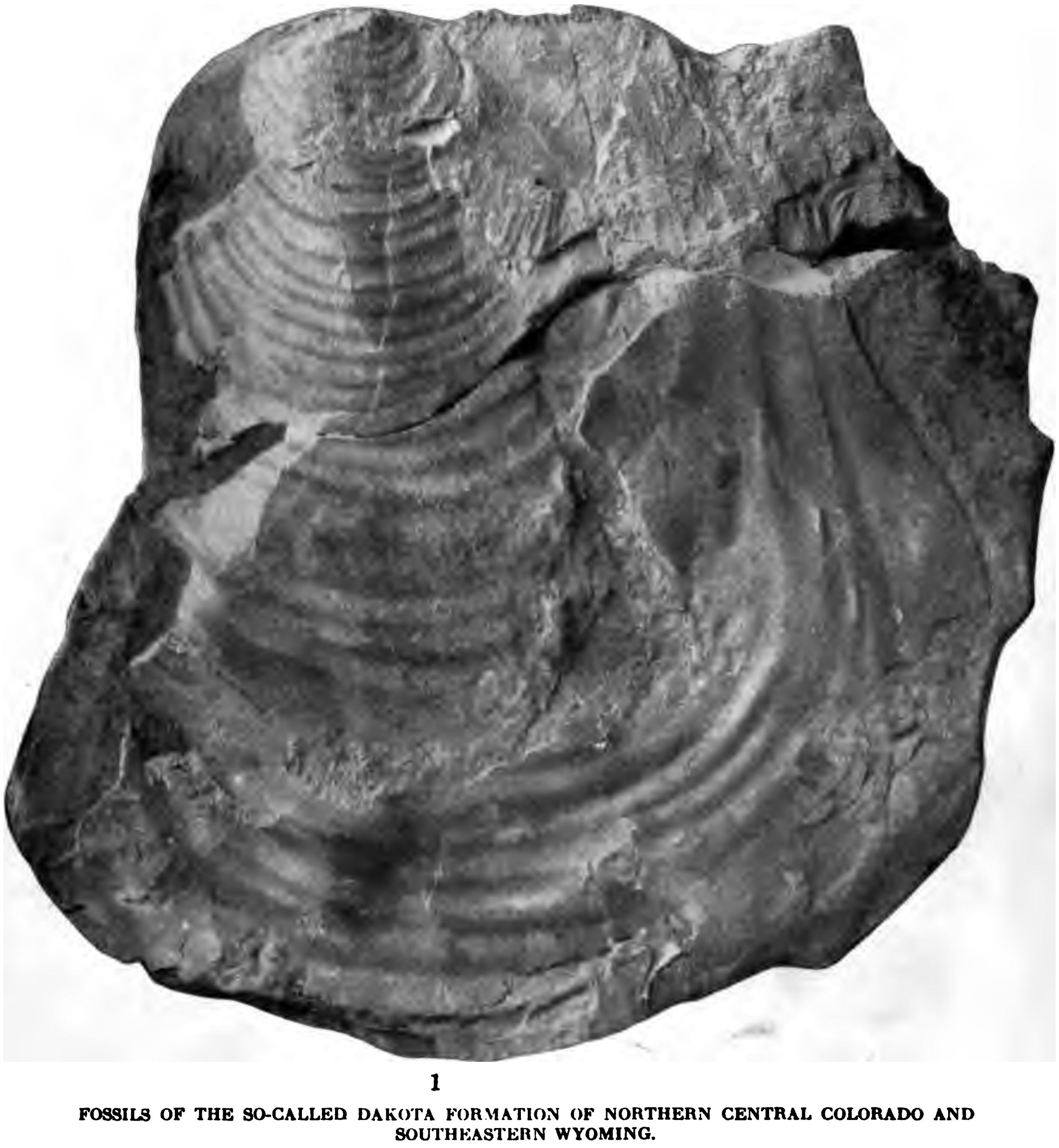
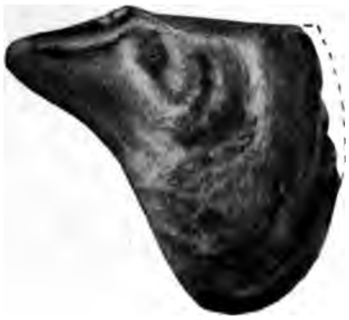


1

FOSSILS OF THE SO-CALLED DAKOTA FORMATION OF NORTHERN CENTRAL COLORADO AND SOUTHEASTERN WYOMING.

Inoceramus bellvuensis Reeside, n. sp., north of Bellvue, Colo. **1, Type specimen (× ¾), left valve (U. S. Nat. Mus. catalog No. 32514); 2, 3, left valves of two specimens (U. S. Nat. Mus. catalog No. 32515).**



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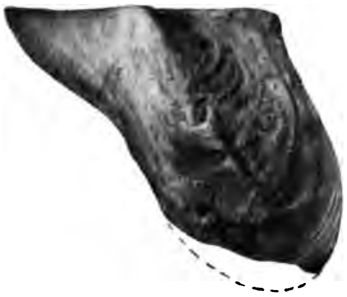

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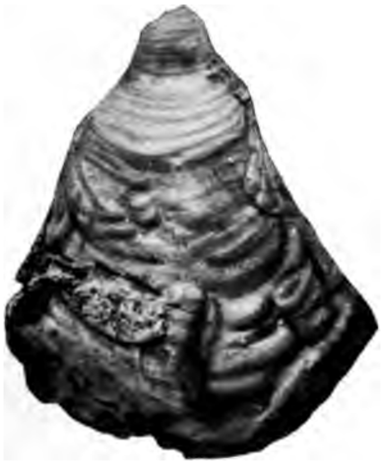

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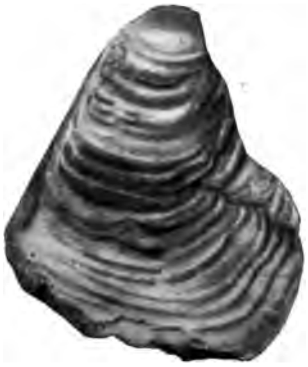

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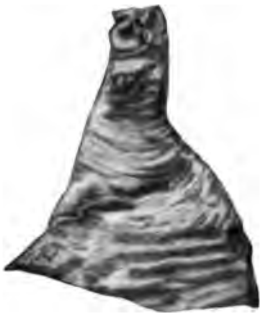

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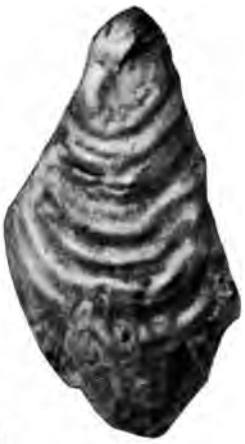

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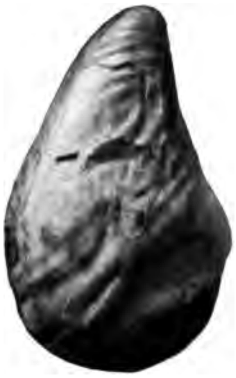

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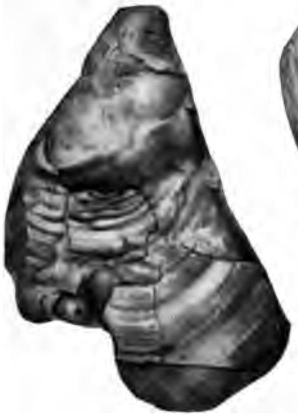

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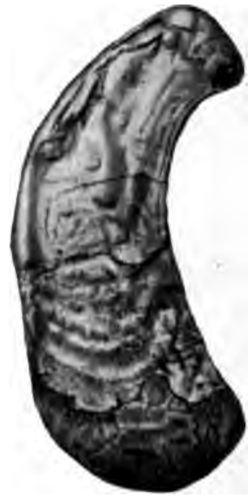

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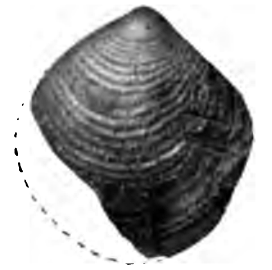
FOSSILS OF THE SO-CALLED DAKOTA FORMATION OF NORTHERN CENTRAL COLORADO AND SOUTHEASTERN WYOMING.

1–5. *Pteria salinensis* White, north of Bellvue, Colo. **1–3,** Left valves of three specimens (U. S. Nat. Mus. catalog No. 32516); **4, 5,** right valves of two specimens (U. S. Nat. Mus. catalog No. 32516).

6–10. *Ostrea larimerensis* Reeside, n. sp., Soldier Canyon, Colo. **6,** Small complete valve, selected as the type (U. S. Nat. Mus. catalog No. 32517); **7, 8,** apical part of two valves, showing the sculpture (U. S. Nat. Mus. catalog No. 32518); **9, 10,** two larger specimens, partly exfoliated (U. S. Nat. Mus. catalog No. 32518).

11, 12. *Ostrea larimerensis* Reeside, n. sp., north of Bellvue, Colo. **11,** Internal cast of an unusually convex specimen (U. S. Nat. Mus. catalog No. 32519); **12,** a nearly complete valve retaining the shell (U. S. Nat. Mus. catalog No. 32519).



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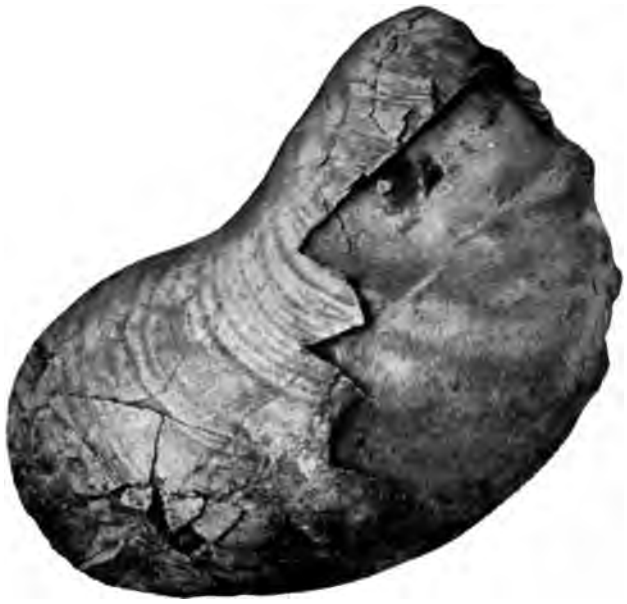

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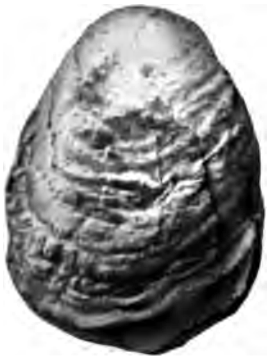

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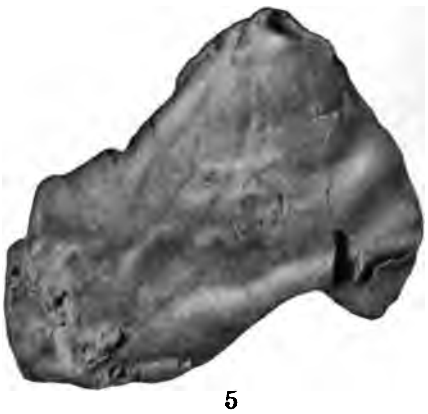

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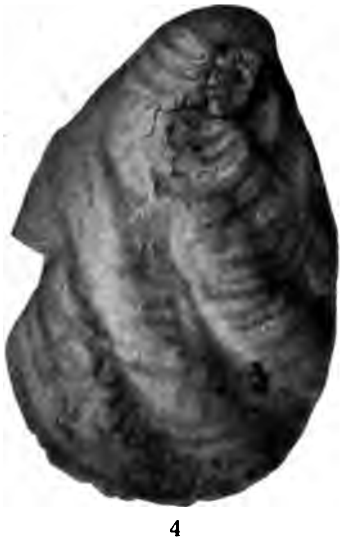

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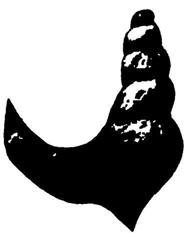

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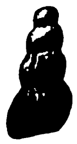

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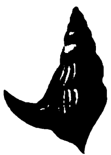


8

FOSSILS OF THE SO-CALLED DAKOTA FORMATION OF NORTHERN CENTRAL COLORADO AND SOUTHEASTERN WYOMING.

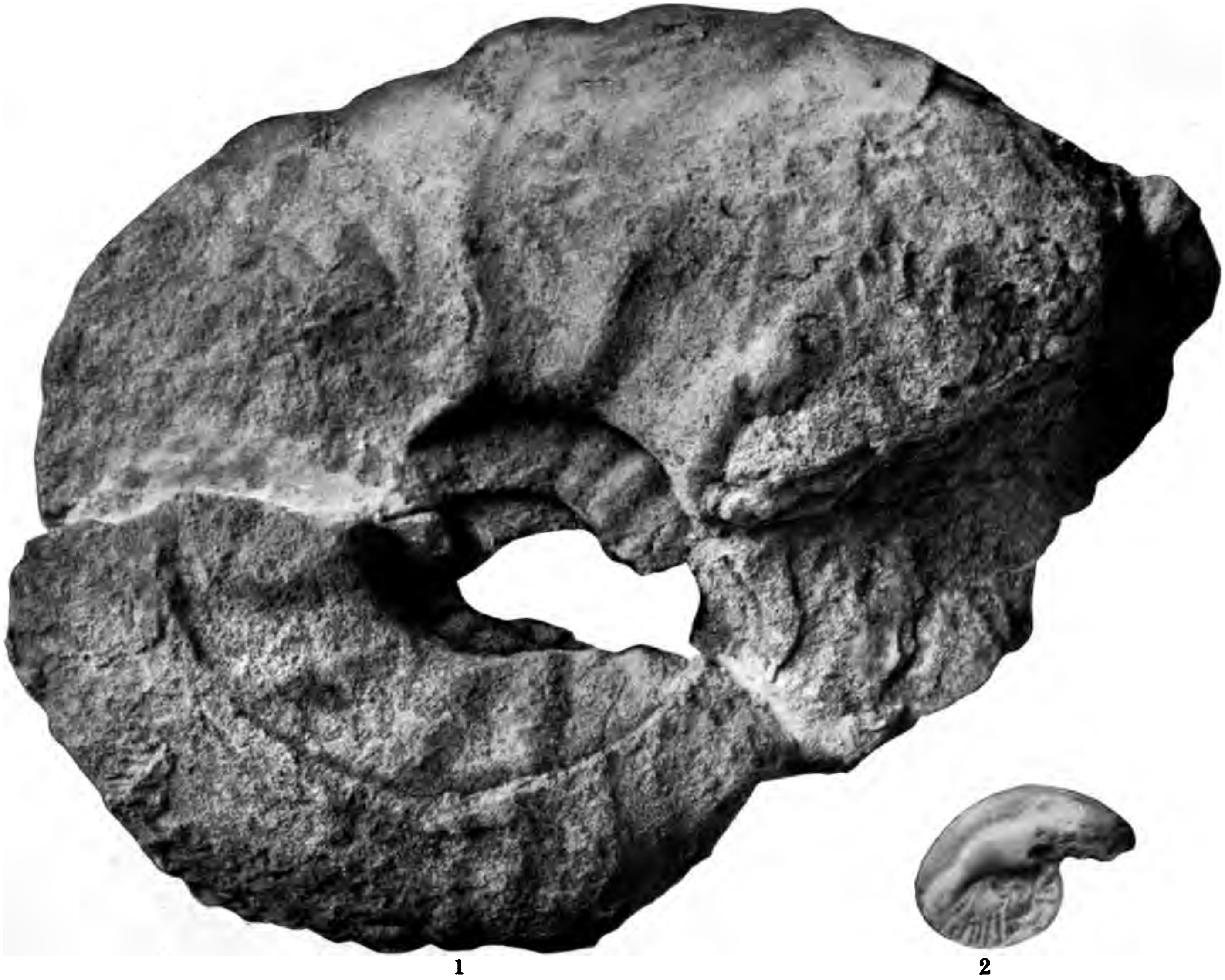
1, 2. *Ostrea noctuensis* Reeside, n. sp., Owl Canyon, Colo. **1,** Type specimen (U. S. Nat. Mus. catalog No. 32520); **2,** Apical part of another specimen (U. S. Nat. Mus. catalog No. 32521).

3, 4. *Ostrea noctuensis* Reeside, n. sp., north of Bellvue, Colo. **3,** Specimen retaining most of the shell (U. S. Nat. Mus. catalog No. 32522); **4,** specimen retaining only the apical part of the shell (U. S. Nat. Mus. catalog No. 32522).

5. ***Ostrea noctuensis*** Reeside, n. sp., Soldier Canyon, Colo. Internal cast. (U. S. Nat. Mus. catalog No. 32523.)

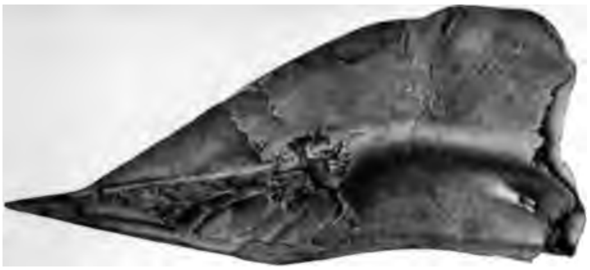
6, 7. *Anchura kiowana* Cragin?, Soldier Canyon, Colo. Two specimens (× 2). (U. S. Nat. Mus. catalog No. 32524.)

8. *Anchura kiowana* Cragin; typical example from Kansas for comparison.



FOSSILS OF THE SO-CALLED DAKOTA SANDSTONE OF NORTHERN CENTRAL COLORADO AND SOUTHEASTERN WYOMING.

1. *Pachydiscus*? sp., 2 miles southeast of Greenacre ranch, Colo. (U. S. Nat. Mus. catalog No. 32525).
2. Ammonite, undetermined, Iron Mountain, Wyo. (U. S. Nat. Mus. catalog No. 32526).



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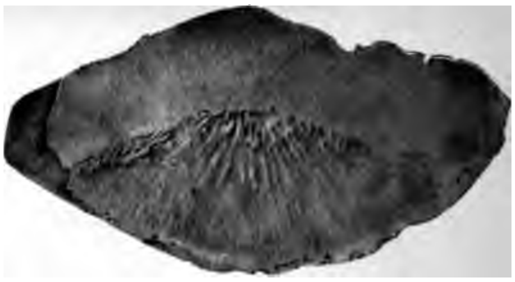

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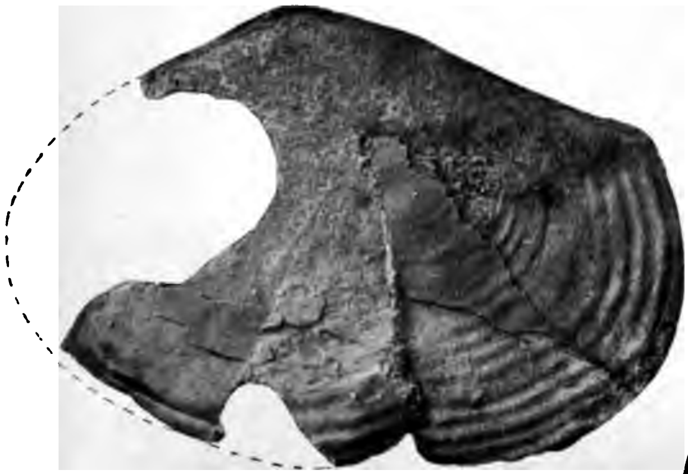

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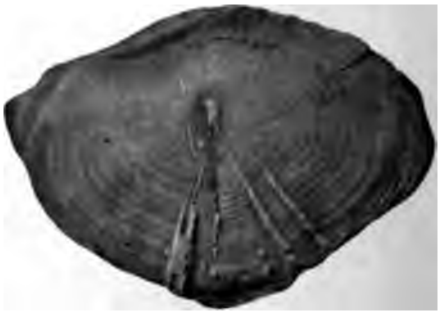

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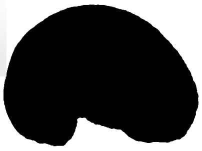

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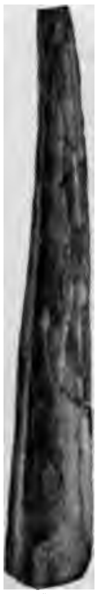

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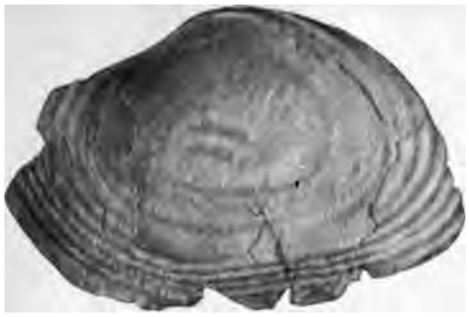

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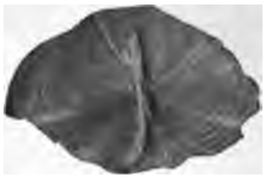

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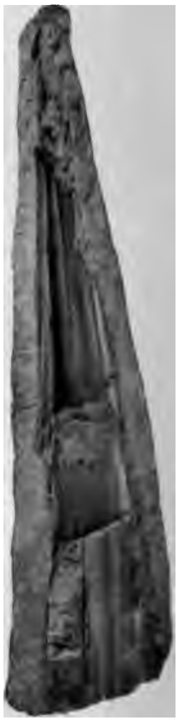

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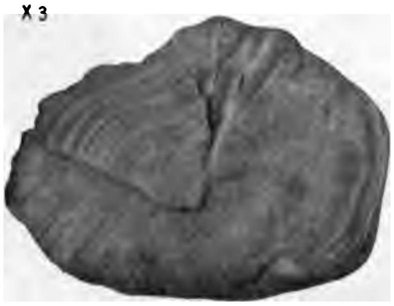

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11 X2

FOSSILS OF THE SO-CALLED DAKOTA SANDSTONE OF NORTHERN CENTRAL COLORADO AND SOUTHEASTERN WYOMING.

1-7. Fish scales and bones, north of Bellvue, Colo. (U. S. Nat. Mus. catalog No. 10771).
8-10. Fish scales and bone, Iron Mountain, Wyo. (U. S. Nat. Mus. catalog No. 10772).
11. Fish bone, Horse Creek, Wyo. (U. S. Nat. Mus. catalog No. 10773).

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DEPARTMENT OF THE INTERIOR
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U. S. GEOLOGICAL SURVEY
George Otis Smith, Director

Professional Paper 132

SHORTER CONTRIBUTIONS TO GENERAL GEOLOGY

1923-1924

W. C. MENDENHALL, CHIEF GEOLOGIST

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DEPARTMENT OF THE INTERIOR
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UNITED STATES GEOLOGICAL SURVEY
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Professional Paper 132—A

ROCK FORMATIONS IN THE COLORADO PLATEAU OF SOUTHEASTERN UTAH AND NORTHERN ARIZONA

BY

C. R. LONGWELL, H. D. MISER, R. C. MOORE,
KIRK BRYAN, AND SIDNEY PAIGE

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W. H. Holmes contributed information on the San Juan district,[4] in a report on field work that was in part contemporaneous with that done by Gilbert farther north and west. The classic reports of Gilbert and Holmes served all practical needs for a knowledge of this sparsely settled region until oil was discovered at Goodridge in 1908. H. E. Gregory [5] and E. G. Woodruff [6] made reports on the geology of the oil field, and Gregory later, in his reports on the Navajo country,[7] described the geology of the region on the south side of the San Juan. The most recent papers of direct interest in the present connection are those by W. B. Emery,[8] C. L. Dake,[9] Dorsey Hager,[10] C. T. Lupton,[11] and R. C. Moore.[12] Numerous papers on adjacent areas, herein referred to, have been of great assistance in making correlations.

TOPOGRAPHY.

The area considered in this report is part of a large arid region that is sparsely settled and difficult of access. It is a typical portion of the Colorado Plateau, characterized by canyons, cliffs, mesas, and buttes. The general plateau surface, averaging between 5,000 and 6,000 feet in altitude, appears fairly regular and continuous in a panoramic view; but Colorado River and its tributaries have cut hundreds of feet below the general level, and Navajo Mountain and the Henry Mountains project conspicuously above it, attaining maximum altitudes of about 11,000 feet. The Henry Mountains are classic as the type locality of the igneous intrusive masses known as laccoliths. Northwest of these mountains are the so-called High Plateaus, lofty forest-clad tablelands with gently irregular surface topography and precipitous borders, which have an average altitude of more than 9,000 feet.

Alternating sedimentary formations of varying resistance exert a strong topographic control. Heavy sandstone and limestone units form vertical cliffs or level mesa tops; shales produce slopes or local areas of badlands. Stream courses cut into sandstone or limestone are confined in narrow, steep-walled canyons; but at horizons of thick shales the valleys are wide, with vertical outer walls made by the overlying sandstones. Typical cross sections of the larger streams show prominent structural terraces or benches, which mark abrupt changes in the character of the rocks.

SEDIMENTARY ROCKS.

GENERAL FEATURES.

The nakedness of the surface rocks and their deep dissection give an excellent opportunity for detailed study, and when the entire region has been systematically surveyed there should be few important problems of correlation left unsolved. But in spite of the apparent simplicity of the geology it is not safe to attempt correlation of widely separated sections without knowledge of the intervening areas, however thorough the study of the sections may have been. Errors have already resulted from such attempts, and a certain degree of confusion now exists as to the exact stratigraphic succession and the proper terminology. Many of the formations are of continental origin, and some have yielded no determinable fossils. Certain of these formations have lithologic characteristics that are remarkably persistent over wide areas; but in many sections two or more formations are strikingly similar in general appearance, and members that are of only local distribution may be confused with formations that are considered the most trustworthy as guides to correlation. In correlating these deceptive formations, therefore, it is desirable to measure sections as close together as possible, and continuous tracing in the field is the most satisfactory method. The rocks are essentially horizontal or dip gently, except for local strong flexures, and the present writers found it possible to follow certain guide horizons essentially without interruption.

The rocks range in age from Pennsylvanian to Tertiary, but the Tertiary formations were not studied in detail. Triassic and Jurassic rocks are the most widely distributed formations on the surface, and they are largely of continental origin. Bright colors prevail, making the region a "painted desert" of great scenic interest. In Utah the older formations are revealed in a few broad anticlines, notably in Cataract Canyon and in the San Juan oil field; and in the adjoining part of Arizona they appear in Marble Canyon.

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[12] Moore, R. C., On the stratigraphy of northeastern Arizona: Am. Assoc. Petroleum Geologists Bull., vol. 6, No. 1, pp. 47-49, 1922. Discusses paper by Hager cited above.

Besides the laccoliths of igneous rocks in the Henry Mountains there are a few igneous dikes and volcanic necks at other places in the part of the Colorado Plateau under discussion. In the High Plateaus, west of the Henry Mountains, there are large areas of extrusive igneous rocks. None of these igneous rocks are here described.

The section exposed in the walls of the Grand Canyon, which adjoins Marble Canyon, is probably better known than any other in the Colorado Plateau, and it is taken as a standard in correlating Paleozoic formations in the region. This section has been studied in great detail by L. F. Noble, and he has recently proposed some changes in the stratigraphic subdivision and the terminology to be used.[13] (See Fig. 1 and Pl. I.) His usage is indicated below, in comparison with the older usage, with a view to making clearer the discussion of Paleozoic formations here presented.

Older usage.		Noble's usage.	
Kaibab limestone		Kaibab limestone	(Permian).
Coconino sandstone		Coconino sandstone	
Supai formation	Upper	Hermit shale	
		Unconformity.	
	Lower	Supai formation (Pennsylvanian and Permian?).	
Redwall limestone	Upper		
		Unconformity (?).	
	Lower	Redwall limestone (Mississippian).	
Unconformity.		Unconformity.	
Pre-Carboniferous formations.		Pre-Carboniferous formations.	

In thus redefining the Supai and Redwall formations Noble has definitely referred the Hermit shale to the Permian on the basis of plant remains first discovered by Schuchert and identified by David White. No fossils have been found in the thick red sandstone at the top of the Supai formation as redefined, and this member may therefore belong either in the Permian or in the Pennsylvanian.

The rock formations studied in southeastern Utah and the adjoining part of Arizona are indicated in the following table:

Rock formations in southeastern Utah and the adjoining part of Arizona.

Age.	Formation.	Character.	Thickness (feet).	Remarks.
Tertiary (Eocene).	Wasatch (?) formation.	Calcareous sandstone, shale, and limestone; pink, white, and varicolored, evenly stratified, soft; composes highest plateaus; crops out in cliffs and forms slopes.	2,000	
		Unconformity		
Upper Cretaceous.	Masuk sandstone.	Yellowish-gray massive sandstone with some sandy shale; grades without break into formation below; a prominent cliff-forming division.	300-500	
	"Masuk shale."	Gray to drab sandy shale containing some thin beds of yellow sandstone.	500-1,000+	
	Blue Gate sandstone.	Yellow to brown irregularly bedded medium to massive sandstone; contains lignite beds up to 4 feet in thickness; forms prominent escarpments.	230-1,000	

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[13] Noble, L. F., in Schuchert, Charles, On the Carboniferous of the Grand Canyon of Arizona: Am. Jour. Sci., 4th ser., vol. 45, pp. 347-362, 1918. Noble, L. F., Paleozoic formations of the Grand Canyon at the Bass trail: U. S. Geol. Survey Prof. Paper 131, pp. 23-73, 1922.

Rock formations in southeastern Utah and the adjoining part of Arizona—Continued.

Age.	Formation.	Character.	Thickness (feet).	Remarks.
Upper Cretaceous.	"Blue Gate shale."	Bluish-drab argillaceous to sandy shale; very uniform in color and texture; forms slopes and badlands; thickness, 1,100-1,200 feet.	2,115-2,250	
	Tununk sandstone.	Yellowish medium to massive irregularly bedded sandstone; contains lignite; forms escarpments and hogbacks; thickness, 60-100 feet.		
	"Tununk shale."	Bluish-drab sandy shale grading to fossiliferous sandstone at base; shale contains abundant *Gryphaea newberryi* and other fossils; thickness, 900-1,000 feet.		
	Dakota (?) sandstone.	Yellow to nearly white sandstone; conglomeratic in part; irregularly bedded; contains lignite locally.	0-100	
		—Unconformity—		
Cretaceous (?) (Lower Cretaceous ?).	McElmo formation.	Maroon to light bluish-gray sandy banded shale; conglomerate; and coarse gritty maroon, yellow, and gray irregularly bedded sandstone; forms escarpments.	125-565	
		—Unconformity—		
Jurassic.	Varicolored sandstones and shales.	Very massive soft light creamy-white, tan, and orange-brown cross-bedded sandstone; grades into very sandy shale; weathers readily in rounded slopes and forms abundant dune sand.	170-1,430	Navajo sandstone of Emery. Included by Lupton in McElmo formation.
	Gypsiferous shales and sandstones.	Pink to red and bluish sandy shale, gypsum in beds up to 5 feet thick, and massive white sandstone; forms badlands; 50-300 feet. Shale, sandstone, and siliceous dark-maroon and light bluish-green limestone; forms distinct escarpment; 30-55 feet.	45-450	Todilto (?) formation of Emery. Horizon of marine Jurassic. Included in McElmo formation by Lupton.
	Navajo sandstone.	Light creamy-yellow, white, pinkish, and buff, highly cross-bedded, very massive calcareous sandstone; weathers in high cliffs and innumerable cones, towers, and domes; forms caves, alcoves, and natural bridges.	500-1,800	Gregory's usage. Included in Wingate sandstone by Emery.
	Todilto (?) formation.	Maroon coarse-grained cross-bedded sandstone; conglomerate; blue-gray hard dense limestone; maroon and brown shale. All in thin irregular beds.	125-249	Gregory's usage. Included in Wingate sandstone by Emery.

Rock formations in southeastern Utah and the adjoining part of Arizona—Continued.

Age.	Formation.	Character.	Thickness (feet).	Remarks.
rassic.	Wingate sandstone.	Reddish-brown very massive sandstone; prominently jointed; outcropping commonly in a single vertical cliff resembling a palisade. Cross-bedded but not so prominently as Navajo sandstone.	250-500	Gregory's usage. Included in Wingate sandstone by Emery.
		Unconformity		
per Triassic.	Chinle formation.	Thick variegated calcareous shales or "marls," fine-grained sandstones, cherty limestones, and conglomeratic limestone. Sandstone most abundant near top of formation.	300-1,000	
per (?) Triassic.	Shinarump conglomerate.	Light-gray to yellow coarse-grained to conglomeratic sandstone, very irregularly bedded and variable in thickness; grades locally into bluish sandy shale; contains silicified wood; forms prominent bench in topography.	0-220	
		Unconformity		
wer Triassic.	Moenkopi formation.	Chocolate-brown to yellowish shale and sandstone, containing locally in upper portion very thin hard limestones. The shale very sandy and grading into shaly sandstones; the sandstone ranging from thin-bedded platy to thick massive beds. Ripple-marked. Contains DeChelly (?) sandstone lentil in middle portion; thickness, 0-200 feet.	304-920	Directly overlies Coconino sandstone where Kaibab limestone is absent.
		Unconformity		
rmian.	Kaibab limestone.	White to yellowish massive more or less dolomitic limestone; in part cherty; lower part increasingly sandy and grading into subjacent sandstone without sharp change. Fossiliferous in part.	0-250	Not continuous.
	Coconino sandstone.	White to tan massive calcareous saccharoidal hard to friable sandstone. In Circle Cliffs not differentiated from Supai (?) formation.	300-1,000	
	Supai (?) formation.	Red to light-yellow shale and sandstone.	380	Possibly Hermit shale.
		Unconformity		
nnsylvanian.	Goodridge formation.	Bluish fine-grained dense, medium to massively bedded limestone; red and grayish-white sandstone, in part petroliferous; red and dark-gray sandy shales. Limestone predominates in lower part of section, sandstone and shale in upper part.	1,582	

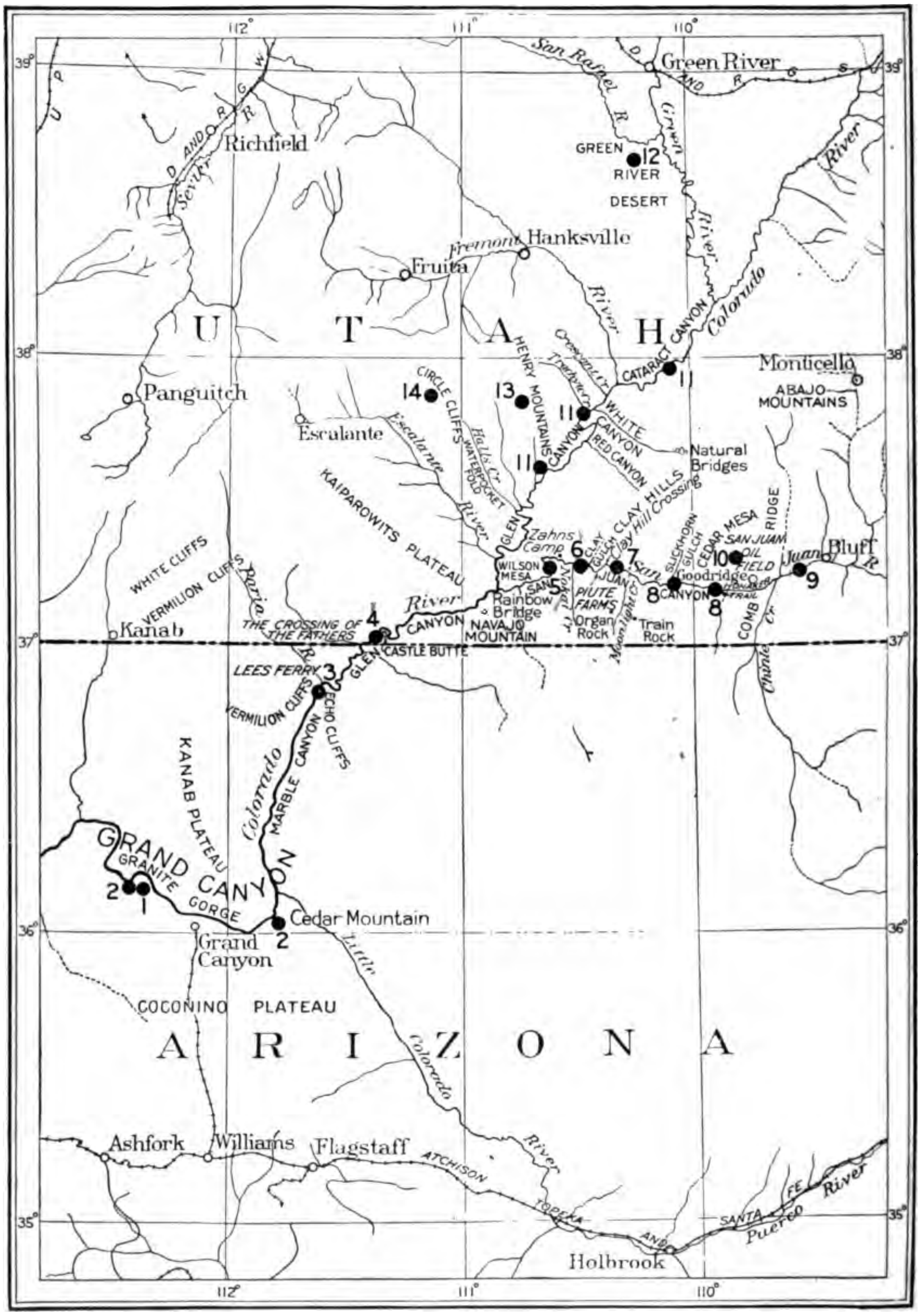

FIGURE 1.--Index map of parts of Utah and Arizona showing location of columnar sections (numbered dots) given in Plates I and II. Nos. 1 to 10 are given in Plate I; Nos. 11 to 14 in Plate II.

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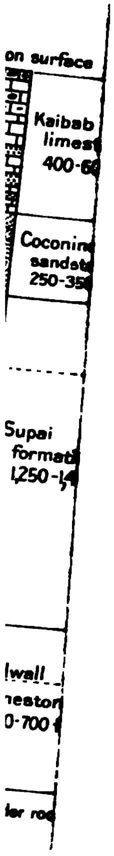

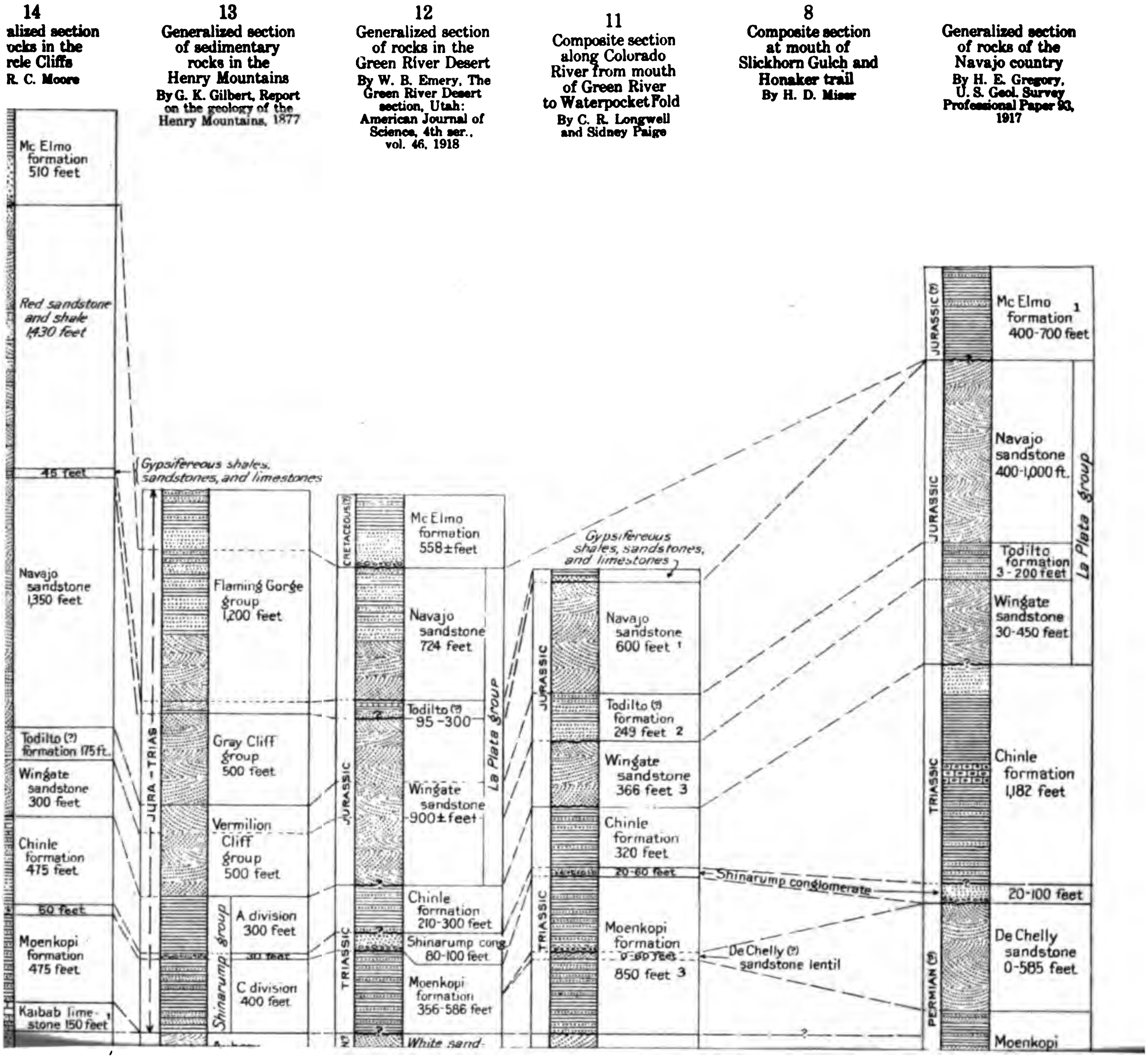

14
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rcle Cliffs
R. C. Moore

13
Generalized section
of sedimentary
rocks in the
Henry Mountains
By G. K. Gilbert, Report on the geology of the Henry Mountains, 1877

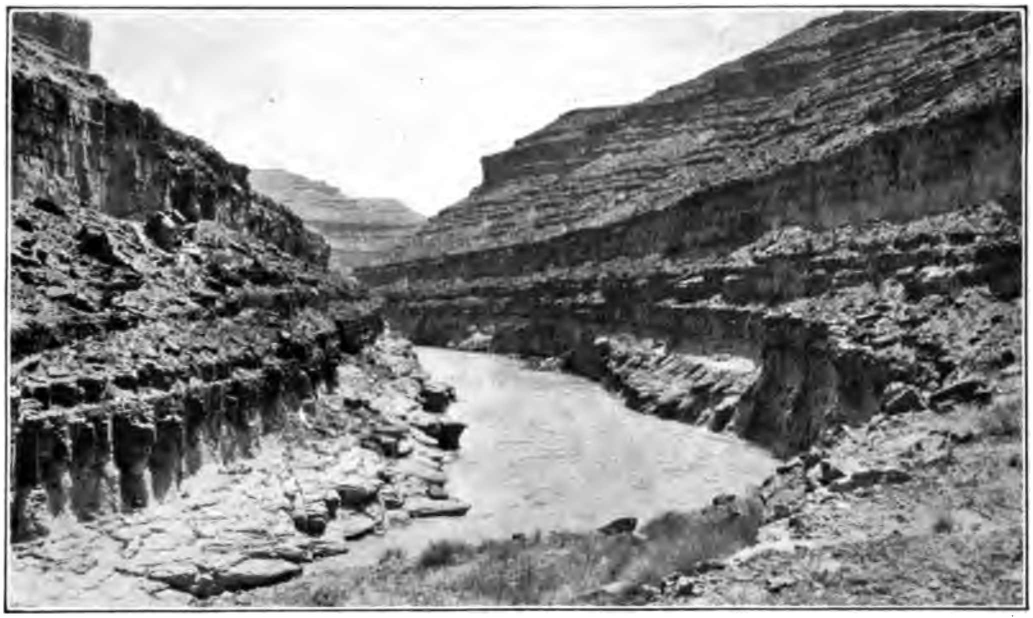
12
Generalized section
of rocks in the
Green River Desert
By W. B. Emery, The Green River Desert section, Utah: American Journal of Science, 4th ser., vol. 46, 1918

11
Composite section
along Colorado
River from mouth
of Green River
to Waterpocket Fold
By C. R. Longwell and Sidney Paige

8
Composite section
at mouth of
Slickhorn Gulch and
Honaker trail
By H. D. Miser

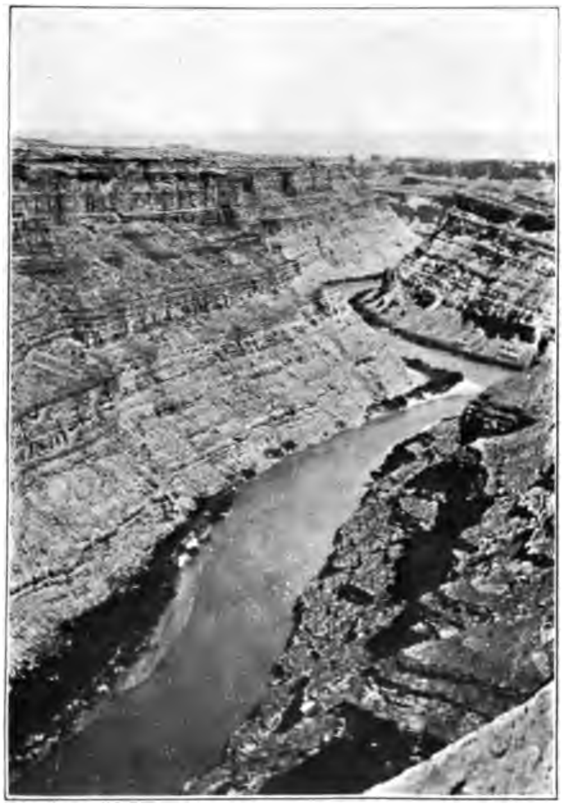
Generalized section
of rocks of the
Navajo country
By H. E. Gregory, U. S. Geol. Survey Professional Paper 93, 1917

Mc Elmo formation 510 feet
Red sandstone and shale 1,430 feet
45 feet
Gypsifereous shales, sandstones, and limestones
Navajo sandstone 1,350 feet
Todilto (?) formation 175 ft.
Wingate sandstone 300 feet
Chinle formation 475 feet
50 feet
Moenkopi formation 475 feet
Kaibab limestone 150 feet
JURA-TRIAS
Flaming Gorge group 1,200 feet
Gray Cliff group 500 feet
Vermilion Cliff group 500 feet
Shinarump group
A division 300 feet
30 feet
C division 400 feet
CRETACEOUS (?)
JURASSIC
TRIASSIC
Mc Elmo formation 558± feet
Navajo sandstone 724 feet
Todilto (?) 95-300
Wingate sandstone 900± feet
La Plata group
Chinle formation 210-300 feet
Shinarump cong. 80-100 feet
Moenkopi formation 356-586 feet
White sand-
Gypsifereous shales, sandstones, and limestones
JURASSIC
TRIASSIC
Navajo sandstone 600 feet 1
Todilto (?) formation 249 feet 2
Wingate sandstone 366 feet 3
Chinle formation 320 feet
20-60 feet
Moenkopi formation
0-60 feet
850 feet 3
Shinarump conglomerate
De Chelly (?) sandstone lentil
JURASSIC (?)
JURASSIC
TRIASSIC
PERMIAN (?)
Mc Elmo formation 400-700 feet 1
Navajo sandstone 400-1,000 ft.
Todilto formation 3-200 feet
Wingate sandstone 30-450 feet
La Plata group
Chinle formation 1,182 feet
20-100 feet
De Chelly sandstone 0-585 feet
Moenkopi



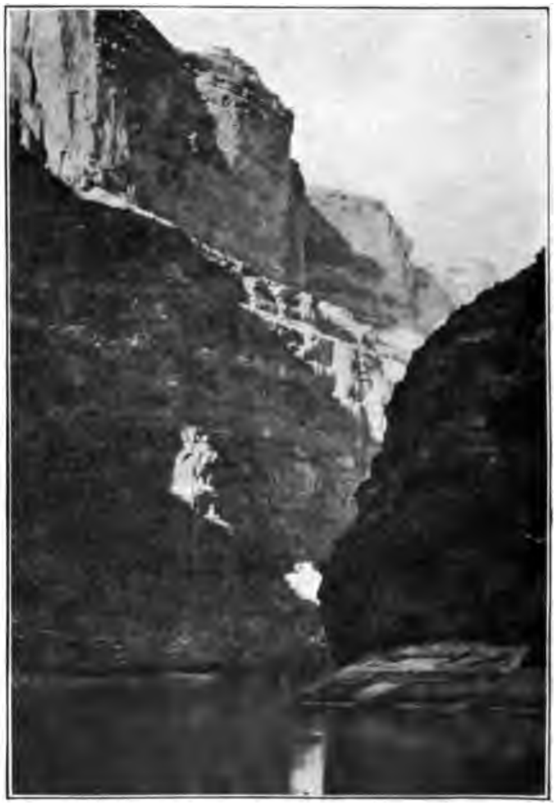
A. VIEW LOOKING DOWN SAN JUAN CANYON, UTAH, AT A POINT 9 MILES BY STREAM ABOVE HONAKER TRAIL.

Canyon has been cut in Goodridge formation. Photograph by Robert N. Allen.



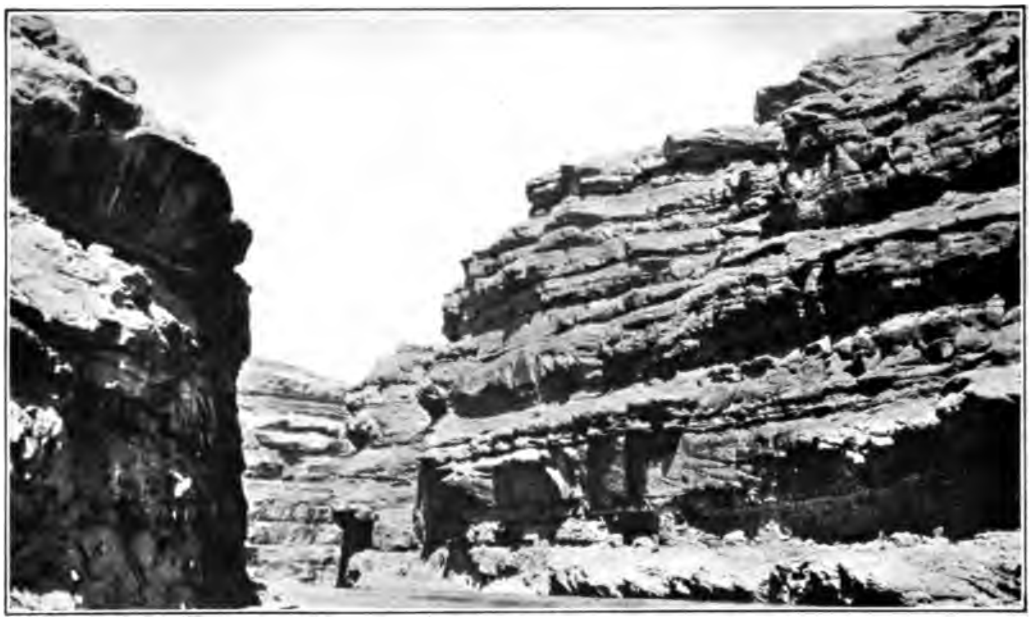
B. VIEW LOOKING DOWN GREEN RIVER TOWARD ITS JUNCTION WITH COLORADO RIVER, UTAH.

Canyon cut in Goodridge formation. Photograph by Sidney Paige.



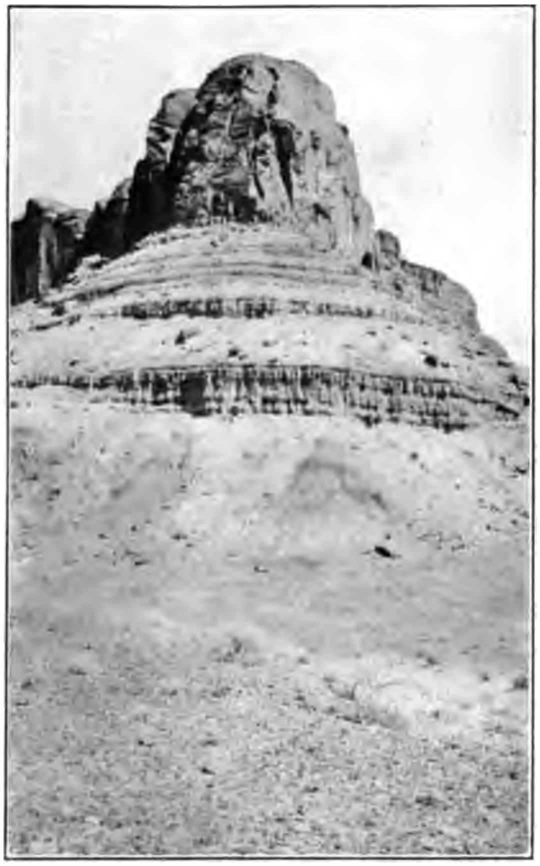
C. VIEW IN CATARACT CANYON OF THE COLORADO, UTAH.

Goodridge formation forms lower part of canyon walls and Coconino sandstone the upper part. These two formations are probably separated by beds that are equivalent to the Supai (?) formation of the San Juan Canyon. Photograph by Sidney Paige.



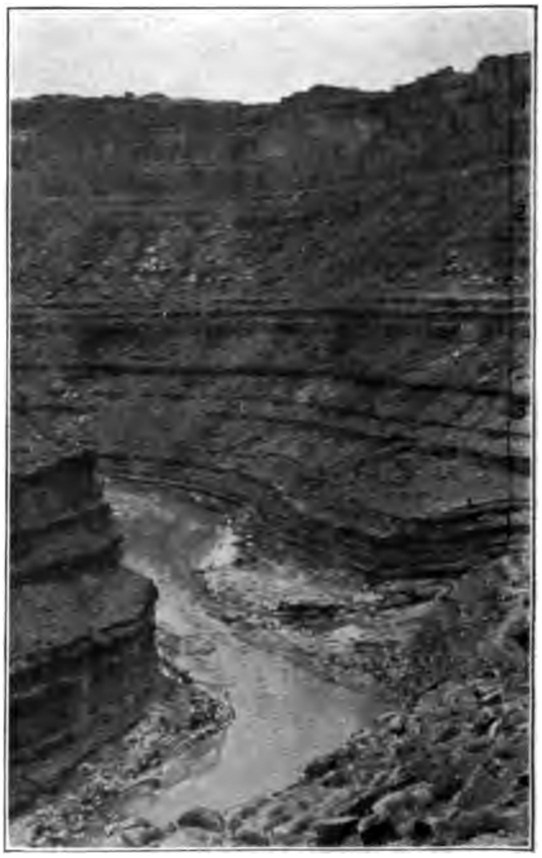
A. VIEW LOOKING DOWN SAN JUAN CANYON, UTAH, AT A POINT BETWEEN CLAY HILL CROSSING AND THE MOUTH OF MOONLIGHT CREEK.

Coconino sandstone forms canyon walls. Photograph by H. D. Miser.



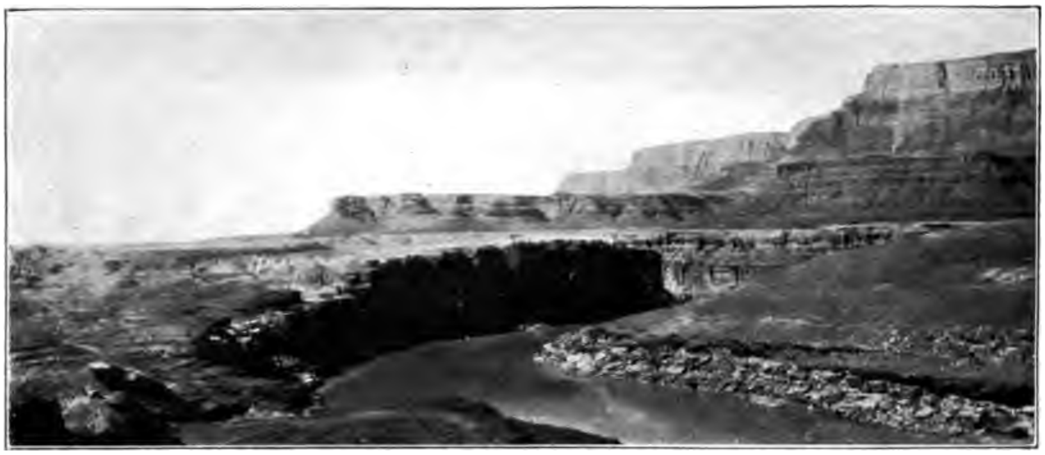
B. VIEW NEAR COLORADO RIVER 2 MILES BELOW MOUTH OF TRACHYTE CREEK, UTAH.

Showing Chinle formation, about 320 feet thick, capped by Wingate sandstone. Part of wide bench in foreground is on Shinarump conglomerate. Photograph by C. R. Longwell.



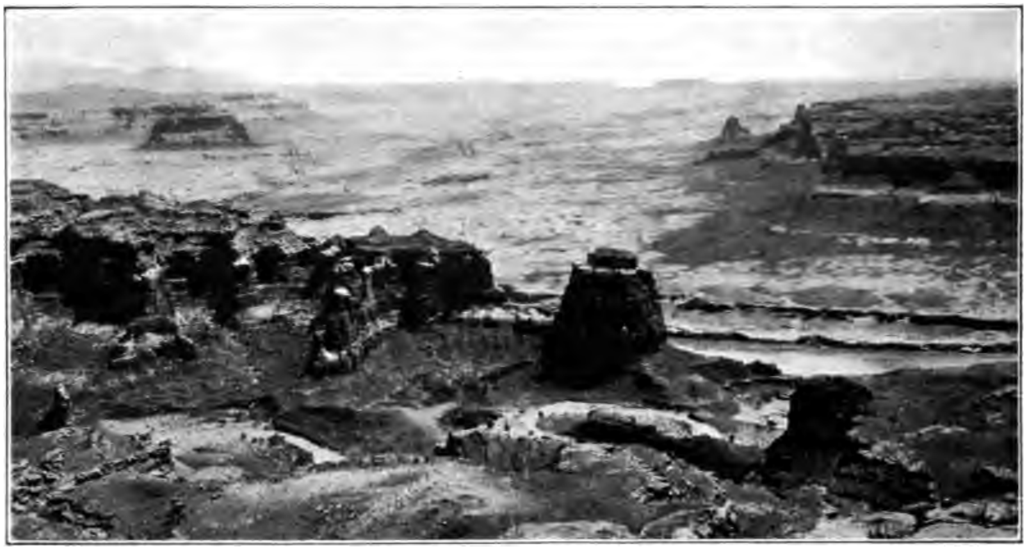
C. VIEW LOOKING DOWN SAN JUAN CANYON AT THE MOUTH OF SLICKHORN GULCH, UTAH.

1, Coconino sandstone; 2, Supai (?) formation; 3, Goodridge formation. The rapid is produced by a boulder bar at the mouth of Slickhorn Gulch. Photograph by Robert N. Allen.



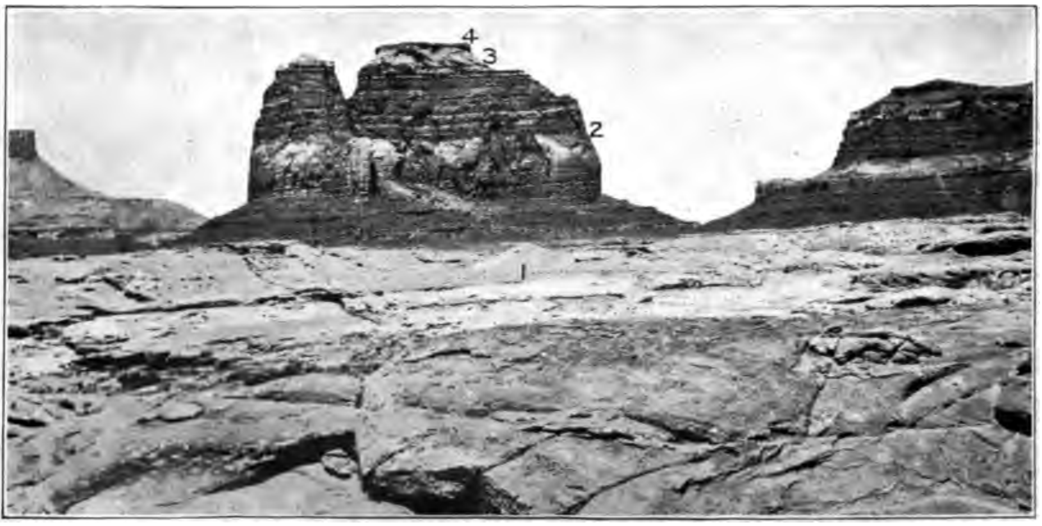
A. VIEW LOOKING SOUTHWEST DOWN HEAD OF MARBLE CANYON FROM POINT NEAR LEES FERRY, ARIZ.

Platform in foreground is underlain by Kaibab limestone; next higher platform reveals the Moenkopi formation and is capped by Shinarump conglomerate; the high Vermilion Cliffs, to the right, are formed by Wingate and Navajo sandstones. Chinle formation is exposed on steep slope below Vermilion Cliffs. Photograph by Kirk Bryan.



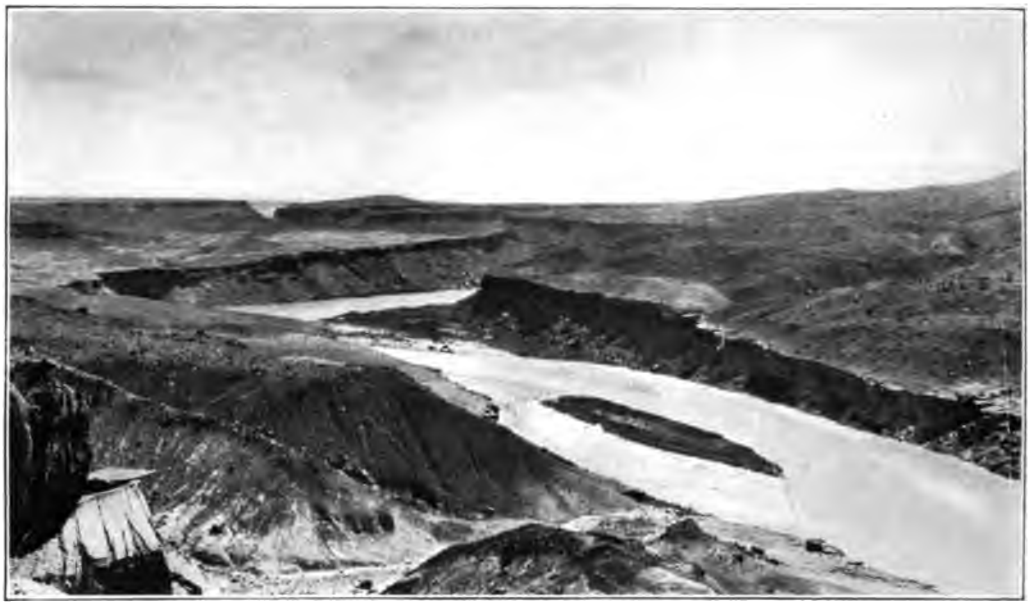
B. VIEW LOOKING UP COLORADO RIVER FROM A HIGH POINT NEAR THE MOUTH OF CRESCENT CREEK, UTAH.

Crescent Creek in foreground. The Colorado is deeply incised in the Coconino sandstone, which forms the light-colored platform. Moenkopi formation in the foreground is stripped from this platform. Photograph by C. R. Longwell.



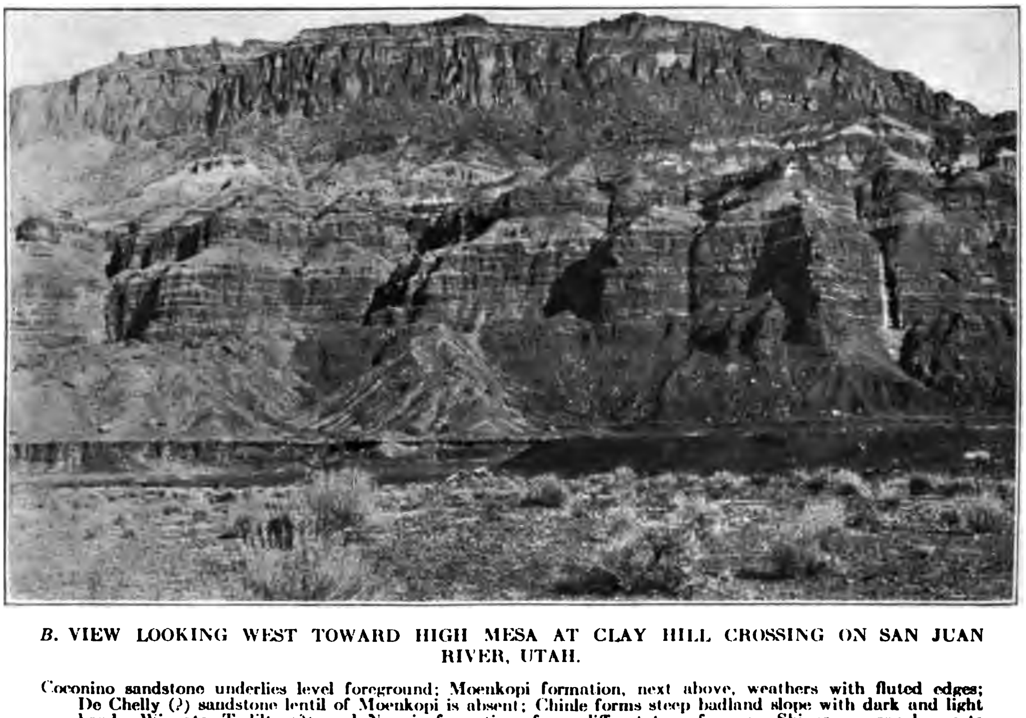
C. EROSION REMNANTS STANDING ON PLATFORM OF COCONINO SANDSTONE NEAR MOUTH OF FREMONT RIVER, UTAH.

1, Coconino sandstone; 2, lower member of Moenkopi formation; 3, De Chelly (?) sandstone lentil of Moenkopi formation; 4, conglomerate at base of upper member of Moenkopi formation. Photograph by C. R. Longwell.



A. VIEW LOOKING UP SAN JUAN CANYON FROM POINT NEAR MOUTH OF CLAY GULCH, UTAH.

Platform is underlain by Shinarump conglomerate, but in foreground terrace gravels and landslide material rest on Shinarump. Moenkopi formation is exposed in lower part of canyon walls. Photograph by Robert N. Allen.



B. VIEW LOOKING WEST TOWARD HIGH MESA AT CLAY HILL CROSSING ON SAN JUAN RIVER, UTAH.

Coconino sandstone underlies level foreground; Moenkopi formation, next above, weathers with fluted edges; De Chelly (?) sandstone lentil of Moenkopi is absent; Chinle forms steep badland slope with dark and light bands; Wingate, Todilto (?), and Navajo formations form cliffs at top of mesa. Shinarump conglomerate is absent. Photograph by Robert N. Allen.

CARBONIFEROUS SYSTEM.

Goodridge formation.—The Goodridge formation, which has been described by Woodruff,[14] is best exposed at the type locality on the Honaker trail in San Juan Canyon near Goodridge, where the canyon has been carved into it to a depth of 1,338 feet without revealing the base. It is of marine origin and consists of sandstone, sandy shale, and cherty limestone, with gray limestone predominating in the lower 500 feet and sandstone and shale in the upper portion. (See Pls. III, *A*, and IV, *C*.) Red is the most common color of the beds in the upper 700 feet. The base of the formation is nowhere exposed, and therefore its relation to older rocks is not known. A less complete section of the formation—about 1,000 feet—is exposed in another anticline east of Goodridge. About 1,500 feet of it is exposed in Cataract Canyon on the Colorado. (See Pls. II, III, *B* and *C*.) A deep well drilled in the Circle Cliffs by the Ohio Oil Co. penetrated in its lower part 1,582 feet of white sandstone and limestone that may represent the Goodridge formation.

Fossils are abundant and are distributed throughout the type section from a horizon near the base to the top. G. H. Girty, who has studied the faunas, makes the following statement:

> The Goodridge formation, as described by Woodruff,[14] comprises two widely different faunas. The lower fauna, which contains almost no true Mollusca, changes abruptly, at bed No. 55 of his published section, to one that contains almost nothing else. The base of the bed as measured by Miser is 314 to 324 feet below the top of the formation. The character of the change suggests that it may not be as significant as the degree of the change might indicate.
>
> The two sections that naturally invite comparison with the Goodridge are the San Juan section, Colorado, to the east, and the Grand Canyon section, to the west. [See Pl. I.] As I suggested in 1912, the general faunal resemblances would tend to correlate the upper part of the Goodridge with the Rico formation in the San Juan region and with the upper part of the Redwall limestone [old usage of Redwall] in the Grand Canyon region. On the same grounds the lower part of the Goodridge would be correlated with the Hermosa formation of the San Juan, which underlies the Rico. In the Grand Canyon section, however, the lower part of the Goodridge has no equivalent that can at present be recognized, but it is closely related faunally to the Magdalena limestone of New Mexico.
>
> Developments of the last ten years have brought about an assignment of the Rico formation to the Permian (?), while the upper part of the old Redwall limestone is referred to the Pennsylvanian and now included in the Supai formation. It is evident that the upper part of the Goodridge can not be correlated with both these formations and yet these assignments be correct. An error evidently exists, but it can not at present be located. The correlations here adopted seem the natural ones, and it is thought better to continue them for the present and to leave adjustments of age determinations to a future day and more satisfactory evidence.

At present, therefore, the upper part of the Goodridge can not be assigned with assurance to any epoch, but the greater part of the formation is certainly Pennsylvanian. It is evident from Mr. Girty's remarks that any attempt to match the Goodridge with a part of the standard Grand Canyon section must be considered as tentative only. This fact should be borne in mind in connection with the columnar sections (Pls. I, II) offered in this paper.

Sandstone and limestone beds of the Goodridge formation supply the oil in the San Juan field, as noted by Gregory and Woodruff. Some of these oil-bearing beds are near the top of the formation, but others are much deeper, the lowest being 1,300 feet below the top. Oil seeps occur at several places along the bottom of the San Juan Canyon. The largest extends for 1¼ miles above the mouth of Slickhorn Gulch, and the oil at this locality comes from westward-dipping beds along and near a fault about 520 feet below the top of the Goodridge.

Supai (?) formation.—The Goodridge formation in the San Juan region and in Cataract Canyon is overlain by red sandy shale and shaly sandstone. (See Pl. III, *C*.) Gregory notes that no definite unconformity is recognized at the top of the Goodridge,[16] but there appears to be a transition to the red beds above through limestone conglomerate that may represent a gradual change from marine to continental conditions. At the mouth of Slickhorn Gulch, on the west side of the San Juan oil field, these higher red beds are 380 feet thick. (See Pl. IV, *C*.) In view of their lithologic character and their position immediately beneath the Coconino sandstone, a possible correlation with Noble's Hermit shale is suggested; but in the absence of fossils the beds are correlated doubtfully with the upper part of Noble's Supai formation, which has a much wider known distribution than the Hermit shale. Woodruff and Gregory referred these red beds to the lower part of the Moenkopi formation, which is now recognized as Triassic. (See Pls. I and II.)

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[14] Woodruff, E. G., op. cit., pp. 80-85.

[16] Gregory, H. E., Geology of the Navajo country: U. S. Geol. Survey Prof. Paper 93, p. 21, 1917.

In the head of Marble Canyon about 500 feet of red shale and sandstone containing beds of blue limestone in their lower part were observed beneath the Coconino sandstone. The highest of these beds may be equivalent to Noble's Hermit shale, but the lowest are probably equivalent to his Supai formation.

Coconino sandstone.—The Coconino sandstone has yielded no determinable fossils, but it is recognized in southern Utah by criteria other than its peculiar lithologic character. In Marble Canyon, southwest of Lees Ferry, Ariz., the sandstone is present in its normal position beneath the Kaibab limestone, which in turn is unconformably overlain by the Lower Triassic Moenkopi beds. In Circle Cliffs the same relations are seen but the Kaibab is much thinner than at Lees Ferry and localities farther west. In and about Cataract Canyon and on the San Juan the Kaibab is absent and the Moenkopi rests unconformably on a thick sandstone that has all the characteristics of the Coconino. Gilbert recognized this relation near Cataract Canyon and referred to the sandstone as the "Upper Aubrey sandstone," the name used at that time for the Coconino in the Grand Canyon. (See Pls. I, II, IV, *C*, and V, *B* and *C*.)

The sandstone here called Coconino has been traced by B. S. Butler,[17] F. L. Hess,[18] H. E. Gregory,[18] C. R. Longwell, and H. D. Miser practically the entire distance from Cataract Canyon to the San Juan oil field by way of White Canyon. The three large natural bridges in White Canyon are stated by Hess and Gregory to have been formed in this sandstone. On the San Juan the Coconino is exposed in a small area on the crest of an anticline at Zahns Camp, but farther upstream it is exposed over large areas, being the surface formation in the part of Moonlight Valley in which Train and Organ rocks are situated and also in the broad dissected plateau between the Clay Hills and the San Juan oil field. (See Pl. IV, *A* and *C*.) The eastern part of the plateau is known as Cedar Mesa. Woodruff[19] states that eastward from Cedar Mesa the sandstone grades completely into red sandy shale on the southeast side of the oil field. This shale and the equivalent sandstone were included by Woodruff[20] and Gregory[21] in their Moenkopi formation. (See Pls. I and II.)

The sandstone is massive and highly crossbedded, and its color is creamy white, though on Cedar Mesa much of it is tan. The grains are fine to medium in size, and as a rule the cement of calcium carbonate is sufficient to make the rock fairly firm, although in places it is friable. The greatest thickness observed is in Cataract Canyon, where it measures nearly 1,000 feet. In the Circle Cliffs only the top of the formation can be seen, but the deep well mentioned above penetrates white sandstone hundreds of feet thick immediately beneath the Kaibab and then passes through beds that are probably the equivalent of the Supai (?) formation. The Coconino, as well as most of the supposed Supai there, consists of white sandstone, so that these two formations can not be separated in the well log. Their combined thickness is 1,550 feet. Near the mouth of Moonlight Creek on the San Juan the thickness of the Coconino is about 600 feet; at the mouth of Slickhorn Gulch, also on the San Juan, it is about 400 feet; at Lees Ferry it is 300 feet; in the Grand Canyon it ranges from 250 to 350 feet; and to the west it gradually decreases,[22] the formation losing its identity in southern Nevada.[23] Thus it is evident that the sandstone thickens consistently toward the northeast in the area of its known distribution.

Kaibab limestone.—Typical Kaibab limestone consisting of white and yellow dolomite and limestone with numerous chert nodules is present in the Circle Cliffs, but its thickness is only 150 feet, as compared with 250 feet at Lees Ferry, 400 to 600 feet in the Grand Canyon,[24] and 1,000 feet in northwestern Arizona and southwestern Utah.[25] (See Pl. V, *A*.) It is not found in Cataract Canyon, in the Henry Mountains,[26] or along San Juan River. (See Pls. I and II.) Thus it appears to thin progressively toward the northeast, with the thickening of the Coconino sandstone in this direction, suggesting lateral gradation of the limestone into the sandstone at the top of the Coconino. It is probable, however, that a large part of the thinning is due to beveling during the erosion interval recorded by the unconformity at the base of the Triassic. This problem is of considerable interest, especially to the paleogeographer, for under the first interpretation the Kaibab shore line certainly lay at no great distance east of the Circle Cliffs, whereas the alternate explanation permits a much greater extension of the Kaibab sea eastward. Study of the Kaibab faunas gives weight to the suggestion that pre-Triassic erosion beveled progressively eastward, for the fauna found in the Circle Cliffs is of the "normal Kaibab" type[27] and not the upper "*Bellerophon* limestone" fauna. Therefore it is probable that the Kaibab present in the Circle Cliffs is lower stratigraphically than the top of the Kaibab in the Grand Canyon and the "*Bellerophon* bed" in the Park City formation of the Uinta country.

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[17] Butler, B. S., The ore deposits of Utah: U. S. Geol. Survey Prof. Paper 111, pp 619-620, 1920.

[18] Oral communication.

[19] Woodruff, E. G., op. cit., p. 86.

[20] Woodruff, E. G., op. cit., pp. 86-87.

[21] Gregory, H. E., Geology of the Navajo country: U. S. Geol. Survey Prof. Paper 93, pp. 29-30, 1917.

[22] Reeside, J. B., and Bassler, Harvey, Stratigraphic sections in southwestern Utah and northwestern Arizona: U. S. Geol. Survey Prof. Paper 129, pp. 57-58, 1922.

[23] Longwell, C. R., Geology of the Muddy Mountains, Nev., with a section to the Grand Wash Cliffs in western Arizona: Am. Jour. Sci., 5th ser., vol. 1, p. 47, 1921.

[24] Noble, L. F., The Shinumo quadrangle, Grand Canyon district, Ariz.: U. S. Geol. Survey Bull. 549, p. 70, 1914.

[25] Reeside, J. B., and Bassler, Harvey, op. cit., pp. 69-76.

[26] Gilbert, G. K., Geology of the Henry Mountains, p. 4, U. S. Geog. and Geol. Survey Rocky Mtn. Region, 1880.

EROSION INTERVAL.

A significant unconformity separates the Paleozoic and Mesozoic sections. There is no perceptible divergence between beds, but an unmistakable surface of erosion lies beneath the Moenkopi formation wherever it has been studied in Arizona, Utah, and Nevada. The unconformity is particularly well shown near Cataract Canyon and about the mouth of Fremont River, where the top of the Coconino sandstone forms wide structural platforms. Recent erosion has stripped away the soft Triassic sediments, and the more resistant Coconino preserves large areas of the pre-Triassic erosion surface almost unchanged, with patches of the basal conglomerate of the Moenkopi still adherering to it here and there in the shallow valleys and rounded divides. Farther back from the main streams recent canyons are cut through the contact, revealing it as a distinct wavy line, overlain by conglomerate in which all the pebbles are of sandstone.

TRIASSIC SYSTEM.

Moenkopi formation.—The Moenkopi formation, of Lower Triassic age, comprises thick beds of shale and sandstone that lie unconformably on the Permian rocks and are at most places unconformably overlain by the distinctive Shinarump conglomerate. As thus defined the Moenkopi consists of several members, which vary considerably in character and thickness from one locality to another. The total thickness ranges from 304 feet in the Circle Cliffs to 920 feet south of the Henry Mountains and along San Juan River. No marine fossils have been reported from the formation in southern Utah, but the lower beds exhibit a regularity and a uniformity of texture that suggest deposition in a large body of water. Farther west and southwest, in Arizona, southern Nevada, and southwestern Utah, the lower part of the formation is clearly of marine origin but the upper part is unmistakably of continental origin.

Along the San Juan the Moenkopi consists principally of red sandy shale and earthy sandstone, with a little gypsum. (See Pl. VI, *B.*) South and southwest of Piute Farms, on the river, a thin bed of cream-colored sandstone is found near the middle of the formation, and this layer thickens gradually toward the south, developing into a massive cross-bedded member which in Train Rock has an estimated thickness of about 200 feet. This sandstone is apparently the same as the sandstone in southeastern Utah called De Chelly by Gregory. He treated the De Chelly as a separate formation, because in most of the region he studied south of the San Juan he found it above Moenkopi shales and immediately underneath the Shinarump conglomerate. He also found that the "Oljato sandstone" of Woodruff is made up of the De Chelly and the Shinarump. (See Pl. I.) The De Chelly sandstone, according to Gregory, is present on the east side of the San Juan oil field, where it is red and thins out toward the north. He also states that the Shinarump conglomerate, wherever it is present on the east side of the oil field, rests on the De Chelly sandstone. It appears probable, therefore, that the upper shales of the Moenkopi were entirely removed in part of the Navajo country by pre-Shinarump erosion. An alternate hypothesis might be that these upper shales are replaced toward the south by the thickening of the De Chelly sandstone.

The sandstone that is here tentatively correlated with the typical De Chelly sandstone of northeastern Arizona disappears entirely near

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[27] See Reeside, J. B., and Bassler, Harvey, op. cit., pp. 66–67.

Piute Farms and Clay Hill Crossing on the San Juan, and it was not recognized in sections for 25 miles north of Clay Hill Crossing.

Along Colorado River below Cataract Canyon the Moenkopi again shows three distinct divisions. The lower division, about 400 feet thick, consists of red and maroon sandstone and sandy shale in regular beds, with a gray conglomerate layer at the base. Shaly beds predominate near the bottom of the section, forming a slope that steepens upward and merges into a cliff made of the more resistant red sandstone. In most sections this cliff is capped with a layer of cross-bedded gray or cream-colored sandstone, ranging in thickness from a few inches to 60 feet. On account of its persistence and its striking contrast with the underlying red beds this member forms an excellent horizon marker. Its stratigraphic position and lithologic character suggest its correlation with the De Chelly (?) lentil on the San Juan.

The upper division of the Moenkopi along this portion of the Colorado consists chiefly of chocolate-colored, red, and gray shale and sandstone ranging in thickness from 350 to nearly 400 feet. Thin-bedded sandstone predominates in the lower part, and the proportion of sandy shale increases upward. The division as a whole has a weak topographic expression, forming a concave slope below the Shinarump cliff. Thin flaggy sandstone layers with strong ripple marks and current marks recur at short intervals in the section. Lenticular layers of cross-bedded sandstone 15 feet in maximum thickness are also common and form the roofs of many old cliff dwellings that are built in reentrants at horizons of shale. All the sandstone beds show evidence of strong fluviatile action, and the shales were probably deposited on flood plains or in shallow temporary lakes. A persistent layer of conglomerate, from a few inches to 25 feet thick, forms the base of the upper division and fills erosion channels in the De Chelly (?) sandstone. This distinct erosional unconformity within the Moenkopi is seen in all sections along Colorado River and its tributaries from Cataract Canyon to Red Canyon, where the gradual westward dip carries the formation below the surface. (See Pls. V and VII, *A*.)

Near Lees Ferry, Ariz., the Moenkopi consists of about 500 feet of red sandy shale and thin-bedded sandstone with seams of gypsum, but 50 miles to the south it has numerous thick beds of red and buff sandstone. Near Jacobs Pools, 25 miles west of Lees Ferry, 12 feet of greenish-yellow sandy shale and 12 feet of yellow sandy and gypseous limestone occur at the top of the formation.

In the Circle Cliffs the Moenkopi consists of 475 feet of chocolate-colored and yellow shale and sandstone with a few thin beds of hard limestone near the top. No gypsum was seen in the formation in this area or along the Colorado, but secondary veins of gypsum traverse the Moenkopi shales near Fruita, in Wayne County, Utah. Only a little gypsum occurs in the Moenkopi of the San Juan region and near Lees Ferry, and the general scarcity of the mineral in the entire region under discussion is noteworthy in view of the high content of primary and secondary gypsum found in both the marine and continental phases of the Lower Triassic in Arizona, southern Nevada, and southwestern Utah.

From the foregoing account and from the columnar sections (Nos. 6 to 9 on Pl. I) it is apparent that the Moenkopi of Woodruff and Gregory in the San Juan region includes not only the typical or true Moenkopi but also the Coconino sandstone and the Supai (?) formation.

Shinarump conglomerate.—The remarkable persistence of the Shinarump conglomerate has excited the wonder of geologists who have studied Triassic sections in different parts of the Colorado Plateau. Within the area under discussion it is generally present at the base of the Upper Triassic, lying on the eroded upper surface of the Moenkopi formation. It is a massive unit of coarse cross-bedded sandstone, in which are interspersed lenses of conglomerate that contain small rounded pebbles of chert, quartzite, and silicified wood. Silicified logs are abundant, and many plant impressions were seen on bedding surfaces. The average thickness of the unit is probably less than 50 feet, but it fills depressions in the underlying beds and at some localities attains a thickness of more than 200 feet. Near the mouth of Nokai Creek on the San Juan the thickness is 220 feet.

The position of the Shinarump conglomerate between two thick shaly formations gives it a strong topographic expression on the sides of valleys, the edge forming a prominent cliff in front of a stripped bench and above a pronounced slope. (See Pls. IV, *B*; V, *A*; VI, *A*; and VII.) The formation is made still more conspicuous in many sections by its dark color on exposed edges; for although the fresh sandstone is ordinarily gray, it appears to acquire an especially dark coat of desert varnish with long exposure. This characteristic is so pronounced that the Shinarump is often referred to as "the black layer" by prospectors and others along the Colorado. Deposits of carnotite in the formation have been mined at several localities.

The exact conditions under which the Shinarump was deposited have been the subject of much discussion, and no conclusion appears to be generally accepted. Whatever the conditions were, it is evident that they must have been almost uniform over a very wide region, for in its essential characteristics the formation differs little in all the sections studied in Utah, Arizona, and Nevada. The uniformity extends even to its thickness, for the total section rarely exceeds 200 feet, and this maximum applies to very small areas. The lenticular and cross-bedded structure indicates the action of shifting streams with fluctuating volume, and the uniformly small thickness evidently indicates a nearly even surface with slight elevation. It is not probable that the region was a desert, for the abundance of silicified wood found in all sections testifies to a climate suitable for the growth of large trees.

Chinle formation.—The Shinarump is believed to be the "basal conglomerate". of the Upper Triassic, for the finer sediments of the Chinle formation in this region follow without any apparent break. Thick beds of marly shale, gray, pink, lavender, yellow, and variegated, form the most conspicuous part of the Chinle. Fine-grained sandstone, cherty limestone, and a few conglomeratic beds are intercalated with the shale. Large silicified logs are found in sandstone layers at several horizons, and there are other indications that the entire deposit is of continental origin. Along the San Juan the thickness ranges from 800 to 1,000 feet, and at Lees Ferry it is about 1,000 feet thick, but it is much thinner to the north, averaging 300 feet along the Colorado above the Waterpocket Fold and 450 feet west of the Waterpocket Fold. This thinning may be due in part to pre-Jurassic erosion, for an erosional unconformity at the top of the Chinle is generally recognized, especially in the northern localities, although it does not appear to be profound.

Wherever the Chinle is exposed over areas of considerable size it gives rise to badland topography. Along the sides of valleys it forms long slopes, broken by low steps at horizons of sandstone or limestone layers. (See Pls. IV, *B;* V, *A;* VI, *B;* VII; and VIII, *B.*)

Limestone is found in the upper part of the formation in beds that range from a few inches to 2 feet in thickness, intercalated with limy shales. The limestone is dense and hard and contains an abundance of chert in nodules or lenses. Layers of intraformational limestone conglomerate are not uncommon. In most places the limestone beds are thin and are limited to a section not exceeding 30 feet in thickness, but at a few localities the individual layers average nearly 2 feet in thickness and make up fully half of a section 50 or 60 feet thick. Sandstone increases in amount toward the top of the formation.

JURASSIC SYSTEM.

General features.—Red, brown, tan, and gray sandstones of Jurassic age form the most prominent outcrops in the area under consideration. The units were traced almost continuously, and their relations for this portion of the plateau were determined without question. There still exists some degree of doubt as to the proper terminology to be applied in the Jurassic section, however, and the reasons for this uncertainty will be discussed briefly.

In the eastern part of the Navajo country Gregory recognized three Jurassic formations,[28] which he thought were equivalent to the La Plata sandstone of southwestern Colorado. For the lowest unit he adopted Dutton's term Wingate sandstone, considering it identical with the section in the Zuni Plateau,[29] to which this name had been applied, and he called the upper formation the Navajo sandstone. In western New Mexico and eastern Arizona these two thick, cross-bedded formations are separated by beds of hard limestone and limy shale, at no place aggregating a thickness of more than a few feet, but so persistent that they were recognized as a distinct unit and named the Todilto formation, from Todilto Park, N. Mex. In his reconnaissance survey Gregory was not able to trace the Todilto continuously to the west, but along the San Juan and in the vicinity of Navajo Mountain he recognized a distinct threefold division that appeared to correspond to the three formations observed farther east. The middle unit along the San Juan contains more sandstone than the typical Todilto, but limestone and limy shale are present at numerous places, and the sandstone formations above and below appear to be identical with the Navajo and Wingate of western New Mexico. Accordingly, Gregory applied the name Todilto to the middle unit tentatively, realizing that the correlation was not certain but only very probable.[30] His Wingate and Navajo of the western Navajo country correspond respectively to Powell's Vermilion Cliff and White Cliff sandstones in the region north of the Grand Canyon and Marble Canyon, but no intervening formation is recognized in that region.

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[28] Gregory, H. E., Geology of the Navajo country: U. S. Geol. Survey Prof. Paper 93, pp. 52-59, 1917.

[29] Dutton, C. E., Mount Taylor and the Zuni Plateau: U. S. Geol. Survey Sixth Ann. Rept., pp. 136-137, 1885.

Emery worked with Gregory in the eastern part of the Navajo country and later made a survey of the Green River Desert, east of the San Rafael Swell, where he recognized three distinct Jurassic formations and applied to them Gregory's names Wingate, Todilto (?), and Navajo.[31] The Todilto (?) of Emery contains fossils and is known to be at the horizon of the marine Jurassic. He noted an apparent threefold division of his Wingate in different sections, the middle member consisting of thin-bedded sandstone and shale; but the height of these thin beds above the base of the Wingate varies at different localities, and therefore he believed that the beds were lenticular and did not represent a constant horizon. Later work, however, indicates that the beds occur at a definite horizon and that the variation in height above the base of the Wingate merely represents a variation in thickness of that formation, perhaps due in part to the unconformity at the top of the Chinle. The thin-bedded unit was traced by Mr. Moore along the San Rafael Swell and the Waterpocket Fold, and other contributors to this report followed the beds continuously in other parts of the region, tracing them to the San Juan and to Rainbow Bridge and other localities where the beds form the unit correlated with the Todilto by Gregory. (See Pl. II.) It appears, therefore, that Gregory's usage has priority and should be retained for the present. It remains for future field work to determine the exact horizon of the Todilto at the type locality. If Gregory's tentative correlation along the San Juan should prove to be correct, then his terminology should be kept permanently and new names should be given to the formations designated Todilto (?) and Navajo by Emery. If the type Todilto is found to be at the horizon of the marine Jurassic, then Emery's tentative usage of the name will be established; but in that case his use of the names Wingate and Navajo should be reconsidered, for it appears that the name Navajo might well be retained for the sandstone that is typically exposed in Navajo Canyon and at Navajo Mountain, and the series of thin beds beneath it (Gregory's Todilto of the San Juan) deserves a new formation name.

In the following descriptions the three names are used in Gregory's sense, with the reservation suggested above regarding the Todilto. Emery's Todilto (?) will be referred to as "gypsiferous shales and sandstones" and his Navajo will be designated "varicolored sandstones and shales." Gregory, during field work since the publication of his reports on the Navajo country, has recognized these two units but has applied only temporary field names to them.

Wingate sandstone.—The Wingate sandstone is the most conspicuous cliff-maker in the region. (See Pls. IV, *B*; V, *A*; VI, *B*; VII, *A*; and VIII.) It is from 250 to 500 feet thick, and commonly the greater part of the total thickness appears as a single massive unit, which is cut by vertical joints and presents an impassable wall at the top of Chinle slopes. In some sections the lowermost beds are lenticular, in part conglomeratic, and apparently fill slight depressions in Chinle shale. These lower beds are obviously waterlaid. The massive, cliff-making portion, which averages about 300 feet in thickness, has indistinct and discontinuous bedding and is cross-bedded on a large scale. These structural characteristics,

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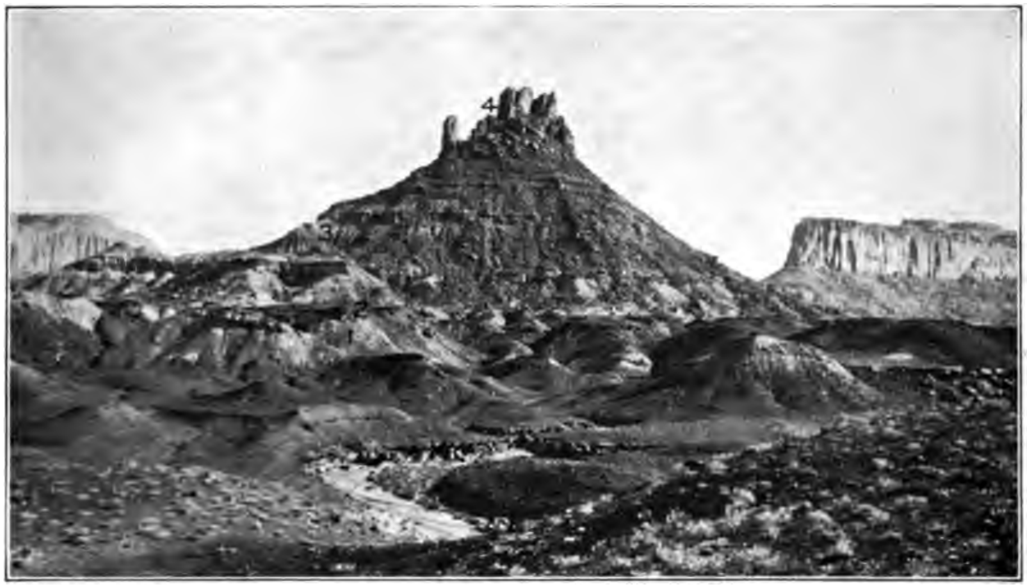
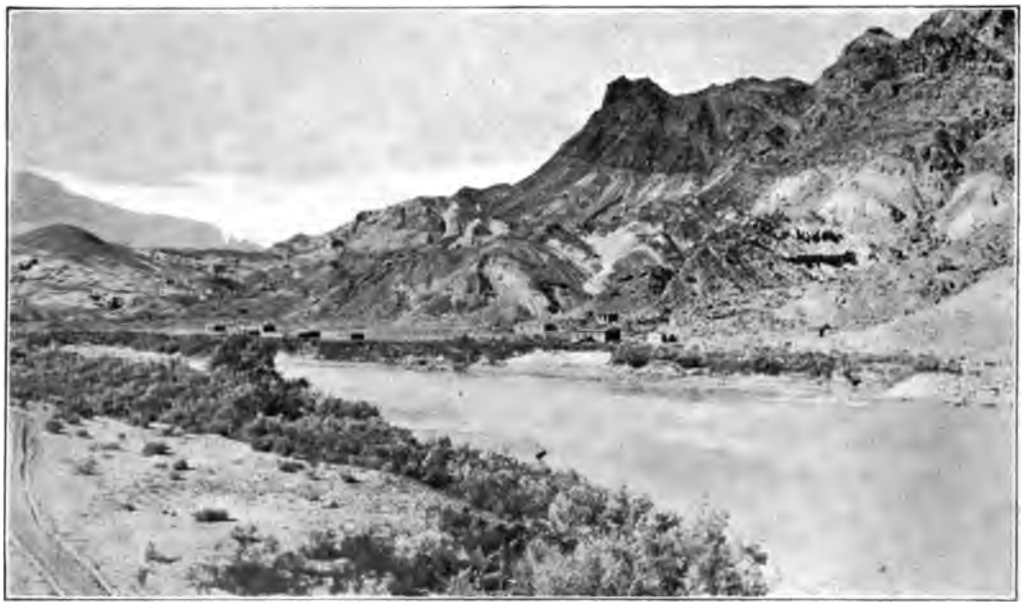
[30] Gregory, H. E., op. cit., pp. 55-56.

[31] Emery, W. B., The Green River Desert section, Utah: Am. Jour. Sci., 4th ser., vol. 46, pp. 551-577, 1918.



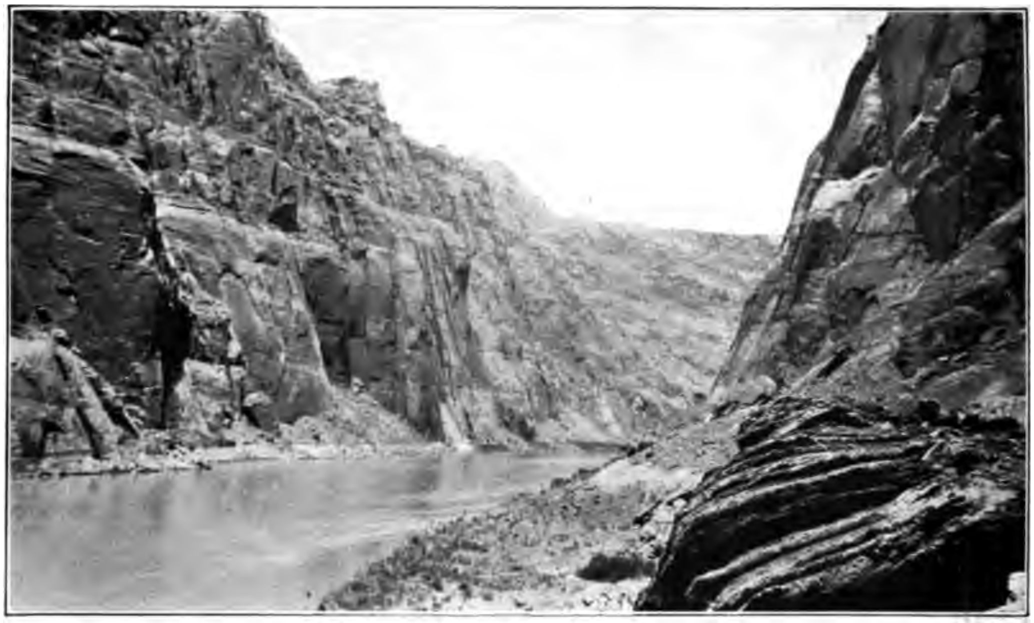
A. CASTLE BUTTE, NEAR MOUTH OF RED CANYON, UTAH.

1, Shale of upper member of Moenkopi formation; 2, Shinarump conglomerate; 3, Chinle formation; 4, Wingate sandstone. Photograph by C. R. Longwell.



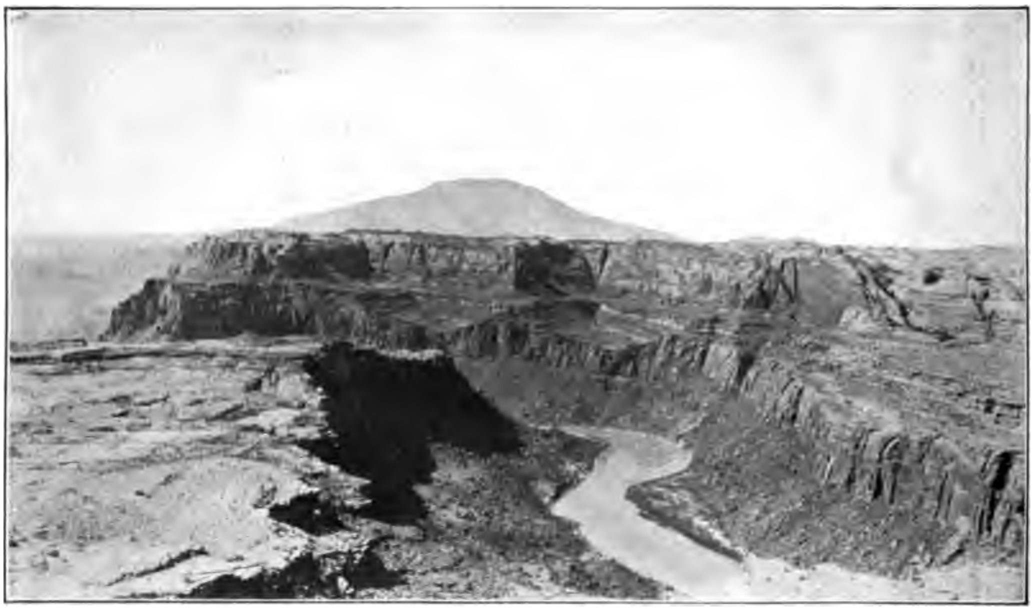
B. VIEW LOOKING NORTH ACROSS COLORADO RIVER AT LEES FERRY, ARIZ.

Small rounded knoll to left stands on Shinarump conglomerate, which dips east. All the higher beds to the right form entire thickness of Chinle formation. Vermilion Cliffs in left background. Photograph by Robert N. Allen.



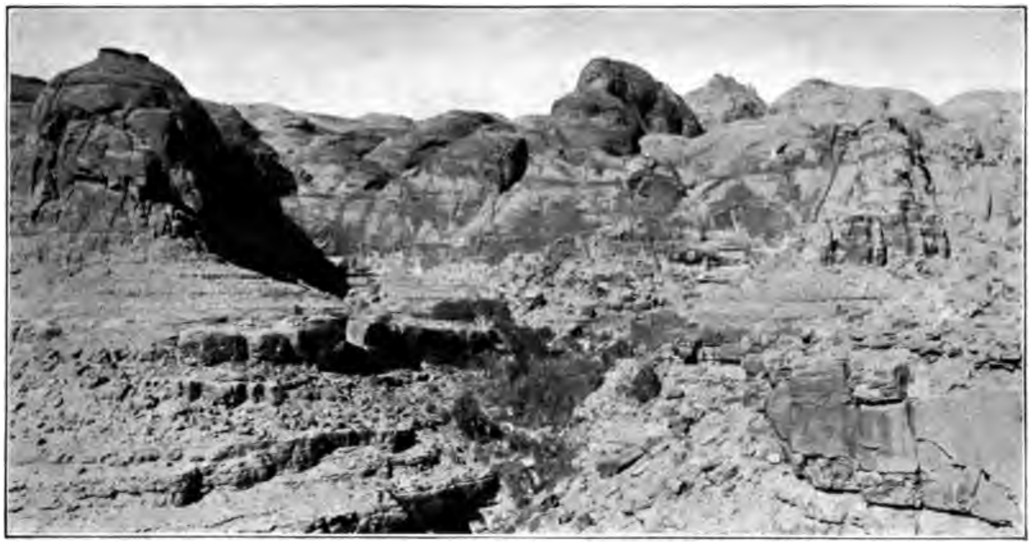
A. VIEW LOOKING NORTHWEST UP COLORADO RIVER TOWARD PROPOSED DAM SITE NEAR LEES FERRY, ARIZ.

Canyon walls are formed by Wingate and Navajo sandstones. Todilto (?) formation is apparently absent. Photograph by Kirk Bryan.



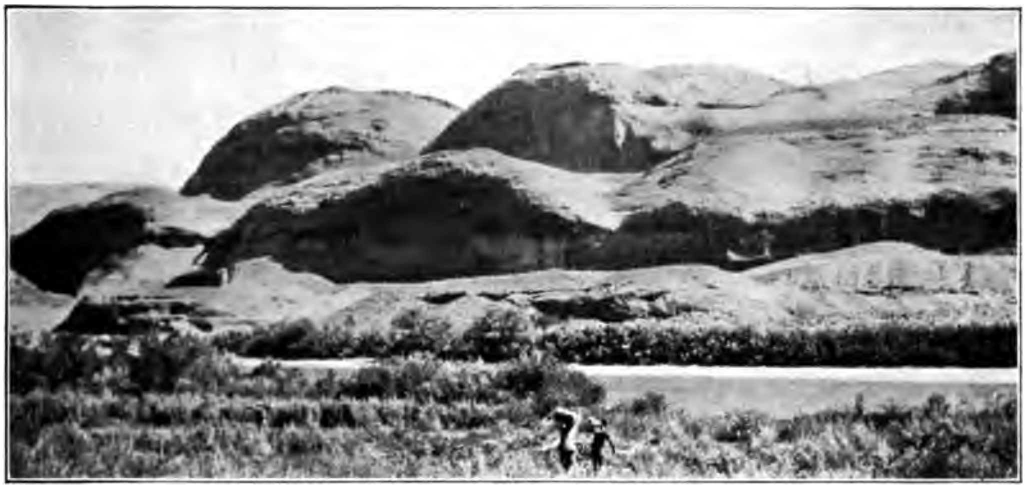
B. VIEW FROM POINT HALF A MILE SOUTH OF SPENCER CAMP, LOOKING SOUTH DOWN SAN JUAN CANYON TOWARD NAVAJO MOUNTAIN, UTAH.

Canyon has been cut in Navajo, Todilto (?), Wingate, and Chinle formations. Photograph by Robert N. Allen.



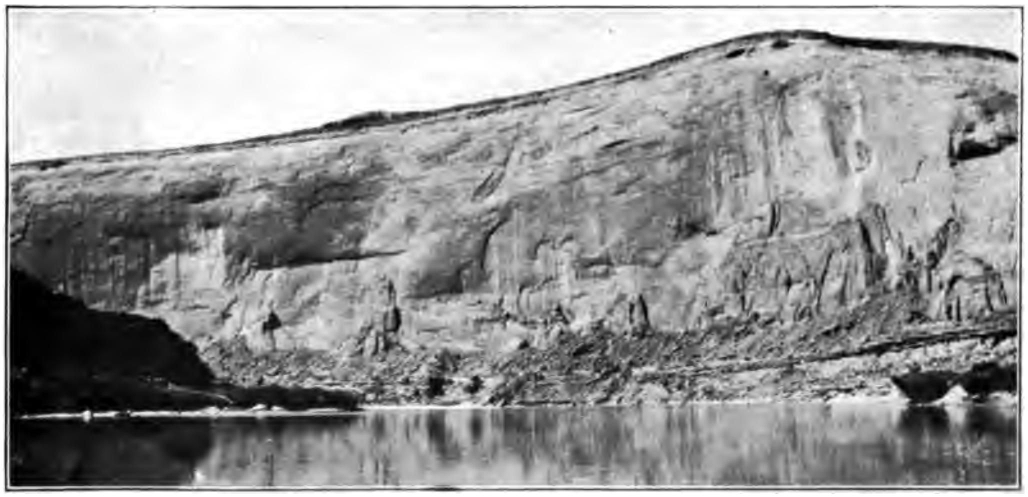
A. VIEW LOOKING NORTHEAST TOWARD WILSON MESA FROM POINT ON WILSON CREEK NEAR SAN JUAN CANYON, UTAH.

Showing bare domes and "mosques" of Navajo sandstone. Todilto (?) formation underlies platform in foreground. Photograph by Robert N. Allen.



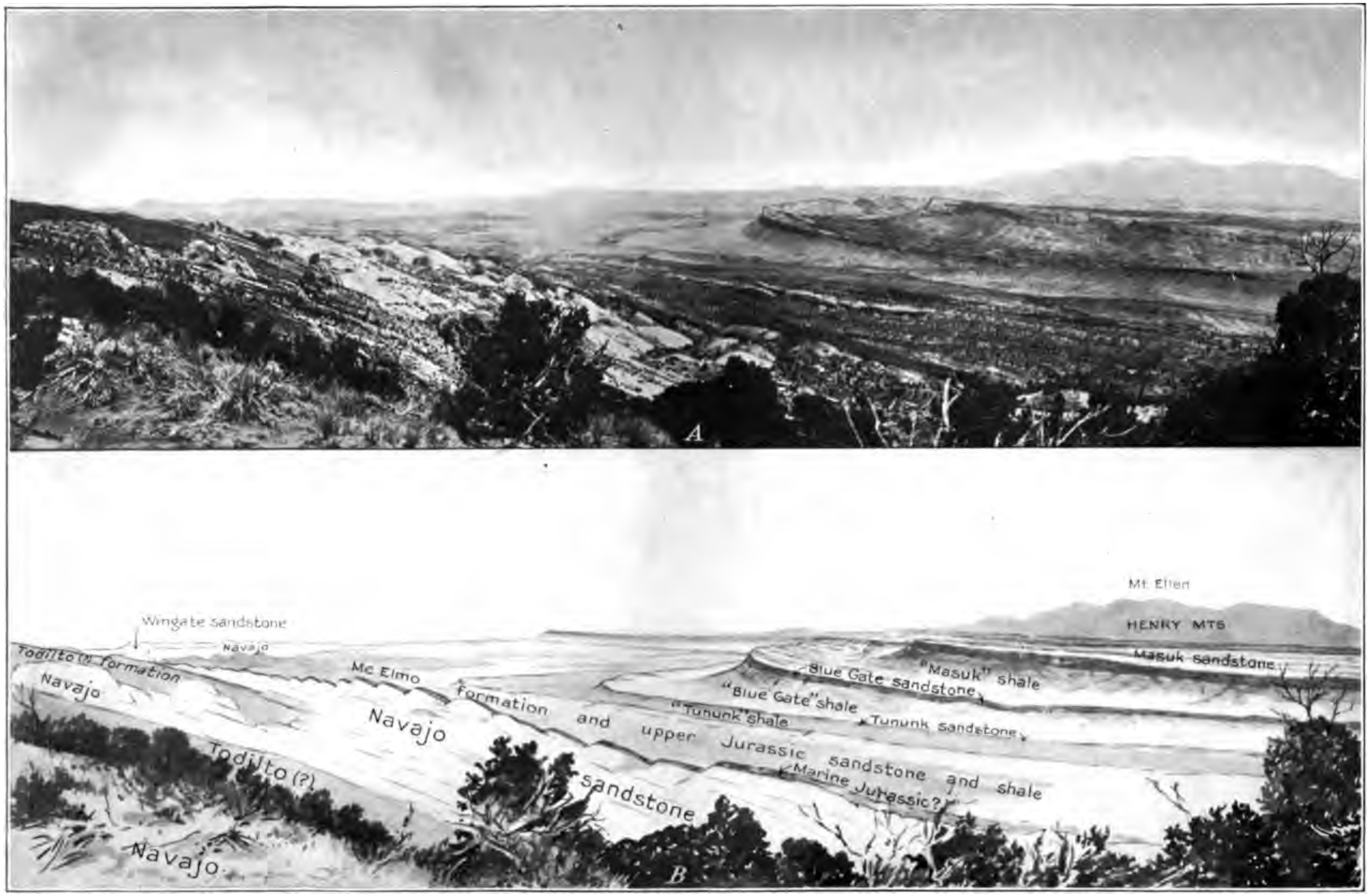
B. VIEW LOOKING ACROSS COLORADO RIVER OPPOSITE SMITHS FORK, UTAH.

Showing colossal domes of Navajo sandstone. Photograph by Sidney Paige.



C. SHEER CLIFF OF NAVAJO SANDSTONE AT WARM SPRING CREEK ON COLORADO RIVER, UTAH.

Photograph by Sidney Paige.



VIEW OF WATERPOCKET FOLD AND CRETACEOUS PLATEAUS BETWEEN THE CIRCLE CLIFFS AND THE HENRY MOUNTAINS, UTAH, AND SKETCH SHOWING THE SURFACE DISTRIBUTION OF THE ROCK FORMATIONS.

Photograph by R. C. Moore.

as well as the universal fineness and roundness of grain, suggest an eolian origin for this principal member. The only fossils reported from the formation are a few dinosaur tracks observed by Mr. Miser on surfaces of the lower lenticular beds at a locality several miles above the mouth of San Juan River.

The color of the sandstone on exposed surfaces gives the cliffs a striking appearance even in a "painted desert"; but the color is reddish brown rather than vermilion as suggested by the old formation name. On unweathered surfaces the rock is typically buff-colored, the darker shade ordinarily seen on cliffs resulting from weathering.

This sandstone forms the Vermilion Cliffs in western Kane County, Utah. Together with the overlying Todilto (?) formation it corresponds in age to Gilbert's Vermilion Cliff group in the Henry Mountains.[32] But the massive sandstones of the Vermilion Cliffs near Lees Ferry, Ariz., and of the Echo Cliffs are made up not only of the Wingate sandstone but of the Navajo sandstone; the Todilto (?) formation has not been recognized and is apparently absent there.

Todilto (?) formation.—The character of deposits in the formation tentatively correlated with the Todilto varies considerably both vertically and horizontally; but the formation is sharply distinguished from the underlying and overlying sandstones by comparative thinness of beds and by undoubted evidence of deposition in water. Measured sections of the formation in the region under discussion range from 125 to 249 feet in thickness. Layers of flinty limestone and of calcareous shale are present in most localities, except perhaps to the north and west, but everywhere sandstone makes up the greater part of the thickness. The lower part is commonly very lenticular and contains considerable conglomerate with small sandstone pebbles. These beds, as well as others higher in the formation, were probably deposited by streams with rapid, shifting currents. The layers of shale and limestone are found for the most part in the middle and upper portions. The shale forms a zone of weakness that commonly causes the overlying Navajo sandstone to retreat behind the Wingate cliffs, leaving benches floored by the lower resistant sandstone of the Todilto (?). (See Pls. VIII, *B*, and IX, *A*.) The limestone beds are lenticular and range from a few inches to 2 feet in thickness. The material is dense, hard, and cherty and is probably of fresh-water origin.

In some sections the transition from the massive Wingate to the thinner beds above appears to be gradual, but at many localities along the Colorado a distinct erosional unconformity separates the two formations, lenticular fluviatile beds filling valleys on the surface of the Wingate. In a cliff the lower sandstones of the Todilto (?) are readily distinguished from the light-colored Wingate by their dark-maroon or reddish-brown color. At higher horizons the Todilto (?) beds vary in color through shades of brown, tan, and lavender. The limestone layers are usually gray.

Navajo sandstone.—Many of the picturesque and grotesque erosion forms common in southern Utah and northern Arizona are carved in the Navajo sandstone of Gregory, which is essentially equivalent to Gilbert's "Gray Cliff group" and to Powell's White Cliffs sandstone. It is exposed over large areas along the Colorado and the San Juan, in the Waterpocket Fold and the Circle Cliffs, and farther west in south-central Utah and forms great tracts of almost impassable badlands, in which domes, "mosques," and "minarets" are common features. (See Pls. VI, *B*; VIII, and IX.) Caves, alcoves, and arches are conspicuous in cliffs of this sandstone, and it forms a number of natural bridges, notably the Rainbow and Owl bridges, near Navajo Mountain.

The thickness varies between wide limits, reaching a reported maximum of 1,800 feet in western Kane County, Utah, and a minimum of about 500 feet south of the Henry Mountains. Along the Colorado and the San Juan the thickness is commonly from 600 to 800 feet, but a few sections measure 1,000 feet. From the Waterpocket Fold westward the thickness is generally above 1,000 feet. There is also a marked change in color from east to west. From the Waterpocket Fold westward a large part of the formation is commonly gray or creamy white, whereas in the region south of the Henry Mountains, around Navajo Mountain, at Lees Ferry, and in Comb Ridge the sandstone is typically tan or buff.

This sandstone is frequently cited as a typical eolian deposit. Cross-bedding of the

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[32] Gilbert, G. K., Report on the geology of the Henry Mountains, pp. 5-7, U. S. Geog. and Geol. Survey Rocky Mtn. Region, 1880.

"tangential" type and on a very large scale characterizes the greater part of the formation, and the laminae of the cross-bedded structure show the abrupt and repeated truncation so commonly seen in "living" sand dunes. True bedding planes are present but not distinct, so that the entire formation stands in some cliffs with the appearance of a single massive layer. Beds of compact limestone from 2 to 5 feet thick lie at several horizons but chiefly in the upper half of the formation. These beds extend laterally from a few hundred feet to half a mile and probably represent deposition in shallow pans or basins. In view of the general high porosity of the sandstone, it would seem that these deposits required a high ground-water level, at least locally.

Gypsiferous shales and sandstones.—The series of beds here designated gypsiferous shales and sandstones is exposed at Bluff, in the Henry Mountains, and farther north, between Kaiparowits Plateau and Escalante River and along the Colorado below the mouth of the San Juan almost to Lees Ferry. (See Pl. X, *A*.) It is also found west of the Kaiparowits Plateau at several localities, notably in western Kane County, Utah, where it is apparently represented by about 100 feet of bluish-gray marl with considerable gypsum. In typical sections the beds consist of gypsiferous shale intercalated with layers of sandstone and some limestone, with an average total thickness of about 75 feet. In 1918 W. B. Emery[33] studied these beds in the Green River Desert and reported the occurrence of marine Jurassic fossils in some of the limestone layers. This fossiliferous series had been noted previously by Gilbert[34] and by Lupton.[35] In some sections there are indications of an unconformity between these beds and the underlying Navajo sandstone.

The beds deserve a formation name, but it appears best to postpone assigning a definite name until the Todilto problem, discussed above, has been finally solved by further field work.

Varicolored sandstones and shales.—The thick series of beds here termed varicolored sandstones and shales includes the greater portion of the rocks in Gilbert's "Flaming Gorge group." These beds reach a maximum thickness of approximately 1,430 feet in the Waterpocket Fold. (See Pl. X, *A*.) Along Colorado River between the mouth of the San Juan and the Crossing of the Fathers the series appears to have a thickness as great as 500 feet, and near Bluff it is from 170 to 270 feet thick. Complete and partial sections are exposed at many localities south and west of the Henry Mountains and northeast of the Kaiparowits Plateau. The series contains a massive cross-bedded sandstone member, tan, red, and gray, which has some resemblance to the typical Navajo sandstone. Other parts of the section consist of thin-bedded sandstone, much of it shaly. East of the Waterpocket Fold the predominant colors are red and tan, but in western Kane County, where the stratigraphic position of the series is occupied chiefly by sandy shale, many of the beds are gray and bluish gray.

Emery considers that this series of beds, as well as those at the horizon of the marine Jurassic, corresponds to the La Plata sandstone of Cross. Gregory limits the La Plata group to his Wingate, Todilto, and Navajo formations.

McELMO FORMATION (CRETACEOUS?).

The McElmo formation, of Cretaceous (?) age, is exposed near Bluff, where it consists of gray, red, and green shale and thin beds of sandstone with two heavy conglomeratic layers, making an incomplete section several hundred feet thick. At places these conglomerates contain carnotite deposits. Along the Colorado below the San Juan partial sections of the formation are made up chiefly of a massive cliff-making greenish-gray sandstone, in part conglomeratic. In western Kane County the McElmo appears to be represented by a coarse conglomerate of undetermined thickness.

CRETACEOUS SYSTEM.

Rocks of known Cretaceous age, all probably belonging to the Upper Cretaceous series, are represented in southern Utah by exposures in the vicinity of the Henry Mountains, along the southern border of the High Plateaus in western Garfield and Kane counties, and in a southeastward projection, of which Kaiparowits Plateau is the chief part, extending into eastern Kane County. (See Pl. X, *A* and *B*.)

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[33] Op. cit., pp. 568–569.

[34] Gilbert, G. K., Geology of the Henry Mountains, p. 6, 1880.

[35] Lupton, C. T., U. S. Geol. Survey Bull. 628, p. 24, 1916.

The total thickness of the Cretaceous section in this region is about 3,500 feet. The rocks consist of alternating divisions of bluish-drab shale and yellowish-brown sandstone, the former appearing in slopes and badlands, the latter in more or less prominent escarpments and hogback ridges. They are divisible into seven distinct units, the basal one of which is doubtfully correlated with the Dakota sandstone. To the rocks above this basal sandstone Gilbert applied the following local names, in ascending order: Tununk shale, Tununk sandstone, Blue Gate shale, Blue Gate sandstone, Masuk shale, and Masuk sandstone. These names were derived from geographic features in the Henry Mountains. As duplication of names is contrary to the practice of the United States Geological Survey, only Gilbert's names for the sandstones have been adopted, and in this report his names for the shales will be used in quotation marks, because of the doubt regarding the relations of this whole succession of sandstone and shale to named units to the north and east. In the present state of knowledge Mr. Moore tentatively correlates the "Tununk shale," Tununk sandstone, and "Blue Gate shale" with the Mancos shale of southwestern Colorado and east-central Utah. The Blue Gate sandstone he tentatively correlates with the Mesaverde formation, the "Masuk shale" with the Lewis shale, and the Masuk sandstone with the so-called "Laramie" sandstone of southwestern Colorado. Some geologists, however, believe that the whole succession corresponds to the Mancos shale.

Dakota (?) sandstone.—As in most of the Cretaceous sections of the Rocky Mountain and Plateau region, there is present in southern Utah a basal sandstone and conglomerate which appears to be homotaxially equivalent to the Dakota sandstone. This sandstone attains a thickness of 100 feet in the escarpment of Kaiparowits Plateau, but in the Henry Mountains district it is much thinner and in places is absent. It evidently overlies the beds beneath it unconformably, for the upper surface of the McElmo is somewhat uneven, the thickness of the upper division of the McElmo is variable, and at one place a slight fold in the McElmo strata was found to have been truncated before the deposition of the sandstone. To these evidences may be added the conglomeratic character of the formation. The color of the Dakota (?) sandstone is yellowish brown to white. The bedding is irregular. Locally thin beds of lignite are present.

"*Tununk shale.*"—The formation above the Dakota (?) sandstone consists of bluish-drab argillaceous and in part sandy shale, called "Tununk shale" by Gilbert. The shale is 900 to 1,000 feet thick in exposures east of the Waterpocket Fold. It is very sandy and grades at the base into extremely fossiliferous brown sandstone. The shale is also fossiliferous, containing especially large numbers of *Gryphaea newberryi*.

Tununk sandstone.—The sandstone overlying the shale just described was called Tununk sandstone by Gilbert. It has a maximum observed thickness of about 100 feet. It is well developed in the vicinity of the Henry Mountains and appears to be present in the Kaiparowits Plateau but was not found southwest of Table Cliff Plateau in western Garfield County. It is light yellowish brown, is irregularly bedded, and locally contains some lignite.

"*Blue Gate shale.*"—Overlying the Tununk sandstone is a shale formation 1,100 to 1,200 feet thick, which resembles the "Tununk shale" in texture and color but lacks the numerous fossils that are characteristic of the "Tununk." To this shale Gilbert applied the name "Blue Gate shale."

Blue Gate sandstone.—A prominent creamy-yellow to light-brown massive and irregularly bedded sandstone succeeds conformably the shale just described. Its thickness in the Henry Mountains, where it was named the Blue Gate sandstone by Gilbert,[36] is 250 to 500 feet, but in the Kaiparowits Plateau and west of Escalante the thickness of this formation is at least 1,000 feet. The sandstone contains lignite, which locally is of very good grade and reaches a thickness of 4 feet west of Mount Ellen. No fossils were obtained from this sandstone, but Lee [37] has suggested that it is comparable with the Mesaverde. It is extremely improbable that this sandstone could represent the Ferron sandstone of Castle

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[36] Gilbert, G. K., op. cit., p. 4.

[37] Lee, W. T., Relation of the Cretaceous formations to the Rocky Mountains in Colorado and New Mexico: U. S. Geol. Survey Prof. Paper 95, p. 50, 1915.

Valley, as suggested by Lupton.[38] The Ferron occurs about 600 feet above the base of the Mancos as there identified and is overlain by 3,000 feet of Mancos shale, whereas this sandstone is 2,200 feet above the base of the Mancos and, as seen in the Henry Mountains, is succeeded by only a few hundred feet of shale. The Cretaceous section of southern Utah appears to be intermediate in character between those of southwestern Colorado, northwestern New Mexico, and northern Arizona and those of central and northern Utah.

"*Masuk shale.*"—Above the Blue Gate sandstone is a light-drab, very sandy shale, which in the Henry Mountains area has a thickness of 500 to 700 feet and to which Gilbert applied the name "Masuk shale." Below Table Cliff Plateau, in western Garfield County, the thickness of this shale is undetermined but is probably more than 1,000 feet. The upper part of the shale contains thin beds and lenses of brown sandstone and appears to grade without break into the overlying formation, the Masuk sandstone.

Masuk sandstone.—The uppermost Cretaceous formation in the region is a massive yellowish-gray sandstone, which east of the Circle Cliffs appears in a prominent table-land bounded by high, sheer cliffs. Its thickness is about 300 feet according to measurements made at its west margin, but Gilbert [39] reports a thickness of 500 feet.

TERTIARY SYSTEM.

In the High Plateaus are found exposures of the youngest stratified rocks of the region, comprising pink, lavender, white, and varicolored limestones, sandstones, and shales of Eocene age. These rocks, which in Garfield and Kane counties have been referred to the Wasatch formation, appear in vertical cliffs and in the fantastically carved, brilliantly tinted walls of canyons that head along the margins of the plateaus. The thickness of the Tertiary sequence in this region is about 2,000 feet. Much of it, especially toward the north, is buried beneath a great accumulation of extrusive igneous rocks.

The Tertiary beds rest with very great unconformity on the Mesozoic rocks, the unconformity being angular as well as erosional. The base of the Tertiary is found in contact successively with all the formations from the highest Cretaceous to the Navajo sandstone, and much of the Navajo was in places removed before Eocene sedimentation. It therefore appears that an important deformative movement, in which such structural features as the Waterpocket Fold, the Circle Cliffs dome, and the gentle flexures south of Table Cliff Plateau were formed, followed Cretaceous deposition, and that before the deposition of the Tertiary strata began this deformed rock series had been planed off by erosion to a nearly level surface, a denudation involving the removal in places of rock strata some thousands of feet in thickness.

LOCAL SECTIONS.

General section of rocks near Lees Ferry, Ariz.

[Measured by Kirk Bryan.]

	Feet.
Brown thin-bedded sandstone and shale, which are probably the equivalent of the beds of marine Jurassic farther north.....	(?)
Navajo and Wingate sandstones: Massive tangentially cross-bedded red to buff sandstone. No parting visible at the center, but upper half has lenses of dense gray limestone 6 inches to 3 feet thick at intervals, and near the top nodules of limonite the size of peas are common. In the Vermilion Cliffs the upper half is distinctly lighter in color. The Todilto (?) formation is apparently absent......................	1,100-1,200
Chinle formation: Blue, green, and red shale; white, gray, purple, and red sandstone; and cherty limestone. Upper part consists of heavy-bedded sandstone and red shale; lower part contains fossil wood.....	1,000±
Shinarump conglomerate: Gray conglomerate with lenses of sandstone and shale; much fossil wood..............................	0-40
Unconformity.	
Moenkopi formation: Red sandy shale and thin-bedded sandstone with seams of gypsum. In places has beds of red and gray sandstone 2 to 6 feet thick, and in one locality 12 feet of gypsiferous limestone at the top. Base, generally, 1 to 10 feet of chert conglomerate............................	500±
Unconformity.	
Kaibab limestone: Yellow limestone with numerous more or less rounded nodules of chert..................................	250
Coconino sandstone: Gray cross-bedded massive sandstone..........................	300
Unconformity (?).	
Hermit (?) shale: Red shale and sandstone............... Unconformity (?) (not observed). Supai formation: Red shale with beds of blue limestone. (observed)..	500±

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[38] Lupton, C. T., Geology and coal resources of the Castle Valley, Utah: U. S. Geol. Survey Bull. 628, p. 32, 1916.

[39] Gilbert, G. K., op. cit., p. 4.

Section about 3 miles southeast of Piute Farms on San Juan River.

[Measured by H. D. Miser.]

	Feet.
Wingate sandstone:	
Massive cross-bedded tan sandstone forming sheer cliff; cut by numerous vertical joints; face of cliff is stained dark brown..........	270
Coarse brown sandstone with pebbles of shale and sandstone up to 2 inches in diameter....	4
Chinle formation: Green and pink marly clay with beds of mottled pink and gray compact limestone as much as 4 feet thick in upper part. Some of the limestone is conglomerate. Pebbles in conglomerate are limestone. Pink and gray flint on slope may have been derived from weathering of limestone. Some parts of clay contain irregular concretions of calcareous earthy material...	830
Shinarump conglomerate: Massive gray sandstone..	10
Moenkopi formation:	
Chocolate-colored shale with some green shale in upper half; light chocolate-colored shale with some thick beds of brown fine-grained sandstone in lower half....................	340
Brick-red sandy shale and earthy sandstone in beds of uniform thickness. The De Chelly (?) sandstone is absent at this place but wedges in farther south near the top of this part of the formation..............................	500
Moenkopi or Coconino: "Transition beds" like those described in section at Zahns Camp.	
Coconino sandstone.	

Section at Zahns Camp on San Juan River.

[Measured by H. D. Miser.]

	Feet.
Chinle formation: Variegated marly shale.	
Shinarump conglomerate: Massive gray pebbly sandstone; forms cliff..........................	50
Moenkopi formation:	
Chocolate-brown sandy shale with a smaller amount of brown shaly and platy sandstone; forms steep slope..........................	325
Brick-red sandy shale and earthy sandstone in even-bedded layers......................	55
Cream-colored cross-bedded massive sandstone; De Chelly (?) sandstone lentil..............	90
Brick-red sandy shale and a smaller amount of red earthy sandstone in even-bedded layers..................................	450
Total thickness of Moenkopi formation....	920
Moenkopi or Coconino ("transition beds"):	
Heavy gray sandstone......................	5
Brown sandy shale and brown shaly sandstone. A bed of gray limestone 1 foot or more thick near top.................................	45
Massive gray sandstone......................	6
Brown sandy shale..........................	5
Massive gray sandstone......................	4
Brown sandy shale and brown earthy sandstone. Contains one or two thin beds of gray limestone....................................	24
Total thickness of "transition beds"......	89
Coconino sandstone: Massive cross-bedded cream-colored sandstone. Two beds of brown sandy shale aggregating 3 feet near the top. Exposure of sandstone extends down to San Juan River......	55

Section on San Juan River north of Spencer Camp.

[Measured by H. D. Miser.)

	Feet.
Navajo sandstone: Cream-colored to yellow massive cross-bedded sandstone........................	200+
Todilto (?) formation:	
Brown fine-grained shaly sandstone with lavender cast...............................	170
Lenses of conglomerate as much as several feet thick; conglomerate composed of sandstone pebbles in sandy matrix..................	
Lavender, brown, and buff fine-grained sandstone in comparatively thin layers..........	50
Total thickness of Todilto (?) formation.	220
Wingate sandstone: Buff fine-grained cross-bedded sandstone; no conglomerate at base.............	330
Chinle formation: Variegated marly shale; concealed almost everywhere by landslides. Formation extends to river, and base is not exposed....	510

Section on north side of San Juan River just above its junction with the Colorado.

[Measured by H. D. Miser.]

	Feet.
Navajo sandstone:	
Gray thin-bedded very fine grained limestone; forms flat top of small mesa.................	4½
Buff massive cross-bedded sandstone..........	310
Todilto (?) formation: Dark and light brown sandstone in comparatively thin beds..............	200
Wingate sandstone: Buff sandstone to water's edge of San Juan River..............................	10+

Section on Colorado River near the mouth of Fremont River.

[Measured by C. R. Longwell. The canyons of Colorado and Fremont rivers are cut in the Coconino sandstone. Above the canyons there is a wide stripped bench on the Coconino, with scattered buttes of the Moenkopi formation.]

	Feet.
Moenkopi formation:	
Conglomerate at base of upper member of formation. Contains angular pebbles of chert, with maximum length of 2 inches, also a few fragments of silicified wood. Firmly cemented by calcium carbonate..............	15
Unconformity.	
Gray sandstone, medium to coarse, strongly cross-bedded throughout. Conspicuous by contrast with red sandstone below. De Chelly (?) lentil..........................	40
Regular beds (a few with cross laminae) of red to maroon sandstone, averaging several feet in thickness, of fine, uniform grain. A few shaly layers, forming narrow benches in cliff.	158
Heavy bed of cross-bedded pink to tan sandstone; persistent, good horizon marker; fine uniform grain.................................	28
Heavy bed of reddish-brown sandstone, grading into gray at the base...................	6

Moenkopi formation—Continued.	Feet.
Fine-grained maroon and red sandstone and sandy shale in regular beds from 6 to 30 inches thick; form steep interrupted slope	115
Red sandy shale, with some layers of cross-bedded fine-grained sandstone; forms slope; muscovite abundant	45
Massive white to gray sandstone, with medium grain	2
Gritty shale and fine-grained sandstone, red to light brown	22
Incomplete thickness of Moenkopi formation	431
Unconformity.	
Coconino sandstone: Gray and tan sandstone, of fine to medium grain, in massive beds and with cross-bedding on large scale. Forms walls of Narrow Canyon and Dirty Devil Canyon. Base not exposed.	

Section on Colorado River near mouth of Crescent Creek ("North Wash").

[Measured by C. R. Longwell.]

	Feet.
Wingate sandstone forms a sheer cliff at least 300 feet high, at top of the steep slope on which the Chinle formation is exposed	300+
Chinle formation:	
Regular beds of pink sandstone, 6 inches to 2 feet thick	12
Coarse sandstone, pink to tan, cross-bedded	25
Gritty shale and fine-grained sandstone, in thin layers	10
Gray calcareous sandstone	1
Pink sandstone in thin beds	27
Massive layer of gray to buff sandstone	6
Calcareous shale in massive layers, containing more or less grit, with a few intercalated thin layers of fine-grained sandstone	155
Heavy bed of dense gray limestone, with chert lenses and nodules	4
Pink calcareous shale	24
Alternating layers of gray limestone and pinkish shale. Limestone layers average 2 feet in thickness and are dense, with abundance of chert	27
Gray, lavender, and yellow shale, banded, with a few thin sandy layers	102
Total thickness of Chinle formation	393
Shinarump conglomerate: Massive coarse-grained, cross-bedded sandstone, with lenses of conglomerate; contains abundance of silicified wood	35
Unconformity.	
Moenkopi formation:	
Lavender, pink, and greenish shale, with a few sandstone layers; green layers prominent near top	72
Gray and yellow sandy shale and fine-grained sandstone	6
Bright-red clay shale	22
Gray, lavender, and yellow shale, with a few bands of dense gray limestone	60
Moenkopi formation—Continued.	
Red and pink sandy shale and fine-grained sandstone	70
Fine-grained cross-bedded red to pink sandstone	2
Alternating layers of gray sandstone and red shale; shale papery, sandstone ripple marked	17
Alternating layers of red and brown sandstone and sandy shale; sandstone layers have current and ripple marks, also a few rain prints; partings of brown paper shale	55
Single bed of massive cross-bedded light-brown sandstone	22
Alternating layers of red and brown sandstone and sandy shale; sandstone layers have current and ripple marks, also a few rain prints.	65
Alternating thin beds of gray sandstone, with very thin partings of brown shale	6
Light-brown conglomeratic sandstone	2
Alternating thin beds of gray sandstone, with very thin partings of brown shale	2
Light-brown conglomeratic sandstone	2
Alternating thin beds of gray sandstone, with very thin partings of brown shale	4
Light-brown conglomeratic sandstone	3
Alternating thin beds of gray sandstone, with very thin partings of brown shale	9
Massive gray cross-bedded sandstone	3
Alternating thin beds of sandstone and shale, yellow, red, brown, and lavender	9
Firmly cemented conglomerate with angular pebbles of chert and hard sandstone; fragments of lustrous coal and of silicified wood also occur as pebbles	10
Total thickness of upper member of Moenkopi formation	441
Unconformity.	
Massive gray sandstone, with marked cross-bedding, loosely cemented with calcium carbonate. De Chelly (?) sandstone lentil	35
Typical red and maroon beds of lower member.	

Section on Colorado River below mouth of Crescent Creek.

[Measured by C. R. Longwell.]

	Feet.
Navajo sandstone: Tan and buff sandstone, cross-bedded on large scale. The sandstone of this locality is an isolated remnant capping a high point	300
Todilto (?) formation:	
Alternating regular beds of calcareous sandstone and gritty shale, with a few layers of limestone conglomerate. Two of the sandstone layers are cross-bedded and tan. Other beds are pink, gray, and lavender. Form long slope	77
Thin layers of red and maroon sandstone, cross-bedded	60
Light-brown and gray cross-bedded sandstone; friable, forming slope; contains hard, concretionary nodules	22
Total thickness of Todilto (?) formation	159

	Feet.
Unconformity (?).	
Wingate sandstone:	
Tan and light-brown cross-bedded sandstone, forming cliff	85
Conglomerate, with pebbles and boulders of sandstone as much as 2 feet in diameter, also pebbles of red clay; calcareous cement	0-4
Massive cross-bedded sandstone, forming almost unbroken cliff. Tan on fresh surfaces, reddish brown on weathered face	280
Total thickness of Wingate sandstone	369
Chinle formation: Forms a long slope below the cliff of the Wingate sandstone.	

Section on Colorado River near mouth of Trachyte Creek.

[Measured by C. R. Longwell.]

	Feet.
Shinarump conglomerate: Coarse-grained gray conglomeratic sandstone, with abundance of silicified wood. Forms low cliff, with shelf above	5-15
Unconformity.	
Moenkopi formation:	
Alternating layers of gray sandstone and greenish shale	5
Lavender, gray, and pink calcareous shale	25
Fine-grained brown sandstone	3
Gray "marl," sandy near base	55
Gray cross-bedded sandstone	3
Greenish-gray and pink shale, paper-thin	4
Bright-red clay shale	5
Yellow, lavender, pink, and gray "marly" shale, in thick beds	60
Alternating chocolate-colored shale and gray to brown sandstone, in thin layers. Ripple marks abundant	60
Massive brown sandstone with strong current marks	2
Alternating chocolate-colored shale and gray to brown sandstone	8
Massive sandstone	2
Chocolate-colored sandy shale	6
Massive cross-bedded sandstone	2
Gray sandstone and chocolate-colored shale, in alternating thin layers	4
Massive gray to brown cross-bedded sandstone	8
Alternating chocolate-colored shale and gray to brown sandstone, with strong ripple marks	22
Light-brown cross-bedded sandstone	5
Chocolate-colored sandy shale	10
Thick layers of sandstone, with thin partings of chocolate-colored shale	11
Alternating gray sandstone and chocolate-colored shale	18
Heavy layers of cross-bedded current-marked sandstone, with thin shale partings; sandstone gray to brown, shale dark chocolate-colored	12
Brown fine-grained sandstone, with thin lamination	6
Heavy layers of pink cross-bedded sandstone, with shale partings	16
Alternating gray sandstone and brown shale; abundant ripple and current marks	22
Moenkopi formation—Continued.	
Fine-grained sandstone with shaly lamination	9
Firmly cemented conglomerate containing angular pebbles of chert and hard sandstone	2
Total thickness of upper member of Moenkopi formation	385
Unconformity.	
De Chelly (?) sandstone lentil (gray to pink cross-bedded sandstone)	20
Typical red beds of the lower member.	

Section on north side of Twomile Canyon, directly east of Mount Holmes, in the Henry Mountains.

[Measured by C. R. Longwell.]

	Feet
Navajo sandstone: Massive tan sandstone, capping a rounded hill	250
Todilto (?) formation:	
Massive fine-grained cross-bedded lavender and gray sandstone	18
Purple and gray shale; forms slope	10
Massive cross-bedded brown sandstone, medium to coarse	9
Red and brown sandy calcareous shale with thin layers of dense gray limestone; forms slope	40
Brown and gray heavy-bedded sandstone with calcareous cement	27
Pink sandy shale; forms slope	14
Gray sandstone and pink sandy shale in alternating beds	11
Reddish-brown and gray medium to fine grained sandstone in heavy layers, some with cross-bedding. Calcareous cement. Layers of unequal resistance, forming steep slope. All beds lenticular; a few lenses conglomeratic	120
Total thickness of Todilto (?) formation	249
Unconformity.	
Wingate sandstone: Tan to reddish-brown sandstone, chiefly in unbroken cliff. Large-scale cross-bedding	366
Unconformity (?).	
Chinle formation:	
Alternating layers of hard fine-grained sandstone and pink sandy shale	14
Pink shale, with a few layers of gray sandstone	22
Gray conglomeratic sandstone, with small pebbles of chert and hard sandstone	2
Heavy bed of fine-grained pink sandstone, loosely cemented	8
Varicolored calcareous shale, with a few sandstone layers	40
Cross-bedded gray sandstone, conglomeratic at base; contains silicified logs	6
Pink and yellow calcareous shale, sandy near top	17
Hard gray limestone, containing chert nodules	2
Lenticular layers of gray sandstone with partings of shale	10
Pink and yellow gritty shale	20

Chinle formation—Continued.	Feet.
Gray and lavender "marl" beds, jointed	34
Cross-bedded gray and lavender sandstone	15
Massive fine-grained sandstone, rich with calcium carbonate and containing cherty nodules	6
Brick-red gritty shale, with layers of gray sandstone	28
Pink and gray calcareous shale or "marl," appearing massive	80
Gray and purplish sandy shale in thin beds	16
Total thickness of Chinle formation	320
Shinarump conglomerate: Coarse conglomeratic massive and cross-bedded sandstone with lenses of conglomerate; abundance of silicified logs; plain impressions of plants on bedding surfaces. Forms vertical cliff	60–120
Unconformity.	
Moenkopi formation: Greenish shale immediately below unconformity. Forms slope.	

Section of Chinle formation at north end of prominent Wingate-capped outlier west of South Fork of Silver Falls Creek, in the Circle Cliffs.

[Measured by R. C. Moore.]

	Feet.
Wingate sandstone: Reddish-brown fine-grained cross-bedded, very massive sandstone, forming single vertical wall; prominently jointed; basal few feet horizontally bedded in thin layers, with ripple marks measuring about 6 inches from crest to crest; thickness estimated	250
Chinle formation:	
Soft limestone, lavender mottled with light greenish blue, weathering in very irregular fragments; partly covered with débris; upper part oxidized and stained to dark purple beneath Wingate sandstone and along joints	5
Light-bluish conglomerate, mostly rather fine-grained; pebbles consist almost entirely of limestone like the associated limestones of the Chinle formation, but there are some flint, quartz, and ironstone pebbles as much as 1½ inches in diameter; upper part grades into very coarse limestone grit, with lines and lenses of fine conglomerate; very massive; crops out in prominent bench	28
Soft shaly limestone, light greenish blue and lavender, mottled; contains locally harder limestone in beds 6 to 10 inches thick which project; this division weathers in a slope	70
Very hard dense fine-grained limestone, light bluish in lower part with mottling of lavender, massive and uniform; locally contains calcite crystals; except for lower part, which is somewhat softer, this bed forms prominent cliff, which in places overhangs	5
Light-blue hard calcareous shale; forms landslide slope	15
Argillaceous limestone, impure, mottled light greenish blue and lavender; weathers in small angular fragments but forms at outcrop a massive vertical ledge; grades upward and downward into hard calcareous shale	3

Chinle formation—Continued.	Feet.
Light-blue hard calcareous shale; forms slope	14½
Hard dense nodular limestone, mottled light greenish blue and lavender; weathers in small irregular-shaped fragments; grades imperceptibly into shale above and below; forms bench	8
Hard calcareous light-blue shale, forming slope	38
Light-bluish shaly soft, very micaceous sandstone, grading into sandy shale	59½
Light-bluish to brown limestone conglomerate, containing pebbles of limestone and chert 3 inches or less in diameter; grades into coarse limy sandstone	2½
Yellowish-brown hard sandy shale grading to ash-gray and lavender shale	53
Grayish-blue to lavender calcareous, highly micaceous sandstone, grading upward into soft massive cross-bedded sandstone; lower part weathers in thin platy fragments	35½
Purple shale, grading upward into yellow and blue shale; sandy, especially in lower part; contains abundant mica; weathers in rounded slopes	13
Brownish-gray thinly laminated to platy sandstone, weathering dark brown; lower part locally conglomerate, containing pebbles of ironstone and jasper as much as 1 inch in diameter	5–6
Sandy shale; upper part weathers to shades of lavender and purple; lower part darker; the proportion of sand increases toward the top; contains satin spar, crystals of gypsum, and mammillary concretions of ironstone with crystalline calcite; weathers in rounded slopes	91½
Brown thin-bedded flaggy sandstone, grading laterally to burnt sienna slaggy ironstone, containing nodules of limonite; this bed forms a bench that weathers irregularly in crumbly fragments	2
Hard calcareous sandy shale, light greenish blue predominant in variegated coloring; weathers in rounded badland slopes	25
Total thickness of Chinle formation	474
Shinarump conglomerate: Grayish-brown irregularly bedded massive sandstone, showing thin cross lamination; some of the weathered surfaces are dark brown or black on account of a surface deposit of iron oxide; contains bluish sandy shale in middle part	85
Moenkopi formation.	

Section of Kaibab limestone west of The Peaks, in the Circle Cliffs.

[Measured by R. C. Moore.]

Moenkopi formation. Kaibab limestone:	Feet.
Yellow dolomitic limestone in massive evenly bedded ledges; weathers in large angular blocks pitted by solution; part contains numerous dendrites of manganese oxide and concretions of a mineral resembling wad; contains fossils; forms resistant cap of prominent bench	37

	Feet.
Kiabab limestone—Continued.	
Light-yellow soft dolomitic massive limestone, filled with angular fragments of chert; weathers in smooth slope; exposed	15
Soft light creamy-yellow thin to medium bedded limestone; weathers in slope; partly concealed	37
White very sandy limestone, rounded sand grains scattered rather evenly; more lime than sand; weathers in thick ledges	34
White medium to coarse grained massive sandstone; rounded quartz grains in a lime matrix	19
White very sandy limestone, rounded sand grains scattered rather evenly; more lime than sand; weathers in thick ledges; forms bench	21
Total thickness of Kaibab limestone	163
Coconino (?) sandstone: White medium to coarse grained moderately soft massive sandstone; rounded quartz grains in a lime matrix; breaks into irregular blocks on weathering; exposed	73

Section of lower beds in front of Kaiparowits Plateau, south of Tenmile Spring, about 15 miles southeast of Escalante, in middle part of sec. 4, T. 37 S., R. 4 E.

[Measured by R. C. Moore.]

	Feet.
"Tununk shale": Bluish sandy shale, grading downward into soft fossiliferous sandstone	400+
Dakota (?) sandstone: Conglomeratic buff to almost white coarse to medium grained sandstone, containing lenses of conglomerate with pebbles as much as 3 inches in diameter; irregularly cross-bedded; forms cliff and prominent bench	90
McElmo formation:	
Red and light-brown sandy shale, interbedded with sandstone of similar color; forms slope partly concealed	55
Light-brown and yellow fine-grained sandstone, cross-bedded in part; occurs in massive layers and forms bench	70
Total thickness of McElmo formation	125
"Varicolored shales and sandstones":	
Red and gray shale and sandstone, interbedded; mostly covered	12
Red, gray, and drab sandstone and shale, in thin alternating beds; considerable variation in color and texture	60
Yellow and buff soft, very massive sandstone; weathers in smooth round slopes, locally with caves and shallow depressions at outcrop	300+
Partial thickness of "varicolored shales and sandstones"	372

Section on Halls Creek about 8 miles above its mouth.

[Measured by R. C. Moore.]

	Feet.
McElmo formation: Reddish-brown and light greenish-gray massive hard, irregularly bedded conglomeratic sandstone; forms prominent escarpment; thickness reduced by erosion	76
"Varicolored shales and sandstones":	
Thin-bedded red sandstone	123
Tan-brown massive soft cross-bedded sandstone, weathering in smooth rounded slopes, partly covered	850
Total thickness of "varicolored shales and sandstones"	973
"Gypsiferous shales and sandstones":	
Light-red and greenish sandy shale; contains beds of white sandstone and gypsum	90
Maroon shale and hard fine-grained quartzitic sandstone; forms escarpment	50
Total thickness of "gypsiferous shales and sandstones"	140
Navajo sandstone: White medium-grained very massive cross-bedded sanstone; forms prominent ridge	600+

Section across Waterpocket Fold near southwest corner of T. 32 S., R. 8 E., at Bitter Creek divide, head of Halls Creek:

[Measured by R. C. Moore.]

	Feet.
Masuk sandstone: Light-yellow massive sandstone, weathering yellowish brown; forms very prominent escarpment; in lower part grades into medium-bedded sandstone	297
"Masuk shale": Yellowish-brown to drab sandy shale; upper part contains beds and lenses of soft sandstone; forms slope beneath escarpment of sandstone above	700
Blue Gate sandstone: Yellow to light-brown medium to massively bedded sandstone forming precipitous cliff; locally contains lignite	230
"Blue Gate shale": Bluish-drab sandy shale, very uniform in color and texture; upper part grades into soft shaly sandstone	1,200
Tununk sandstone: Yellowish-brown medium to massively bedded sandstone	50–75
"Tununk shale": Bluish-drab sandy shale, uniform in color and texture; includes very fossiliferous thin yellow sandstone at base	975
Dakota (?) sandstone: Light-yellow soft irregularly bedded sandstone, grading upward into sandy shale; contains two thin beds of impure lignite 9 and 20 inches thick	15
McElmo formation:	
Grayish-blue, maroon, and purple banded soft sandy shale, weathering in valleys and badlands	415

McElmo formation—Continued.	Feet.
Grayish-white to light bluish-green conglomerate and sandstone; contains pebbles as much as 2 inches in diameter; consists in part of thick beds and lenses of coarse conglomerate and in part of coarse gritty very irregularly bedded sandstone	150
Total thickness of McElmo formation	563
"Varicolored shales and sandstones":	
Red and gray banded sandy shale grading to soft thin-bedded sandstone	90
Tan-brown massive soft cross-bedded sandstone, weathering in smooth rounded surfaces	260
Reddish-brown and bluish-gray very soft shaly sandstone, weathering readily, forming valley; partly covered	470
Tan-brown massive soft cross-bedded fine-grained sandstone, weathering in smooth rounded surfaces	340
Total thickness of "varicolored shales and sandstones"	1,160
"Gypsiferous shales and sandstones:"	
Light-red and bluish-gray shale and sandstone; gray to white sandstone in alternating beds; contains several beds of bluish to white gypsum as much as 3 feet thick; the gypsum occurs also in numerous thin veins	400
Dark to light red sandy shale, containing two beds of very hard reddish and light green mottled dense siliceous massive and flaggy limestone that forms escarpments	50
Total thickness of "gypsiferous shales and sandstones"	450
Navajo sandstone: White to very light cream-colored sandstone, locally stained light orange-red in middle and lower parts; capped by bed of coffee-brown sandstone, 10 feet, and light tan, highly cross-bedded sandstone, 8 feet. Very massive, highly cross-bedded on large scale; the cross-beds are etched in relief by weathering; crops out in high, prominent "reef" whose surface is marked by numerous conical tepees, mosques, and rounded domes	1,400
Todilto (?) formation: Dark-red to maroon cross-bedded sandstone, medium to coarse grained, thin to medium bedded; some beds hard, others soft; bedding very irregular; locally contains soft maroon sandy shale; thickness in part estimated.	160
Wingate sandstone: Red very massive hard fine-grained sandstone, of uniform color and texture, cross-bedded but bedding not prominent, much jointed; crops out as single ledge making a vertical cliff or palisade	340
Chinle formation:	
Light-bluish hard calcareous shale, mottled with lavender; upper part stained purple; weathers in rough angular blocks; forms slope	48

Chinle formation—Continued.	Feet.
Massive light greenish-blue limestone conglomerate, composed of pebbles of limestone, quartz, jasper, and sand in a lime matrix	2
Alternating beds of light bluish-green limestone and shale, mottled with lavender; the shale is hard and calcareous, forms slopes, and grades without demarcation into limestones that are nodular, hard, and massive and form projecting ledges	146
Sandy shale and sandstone, yellowish brown, yellow, dark brown, blue, purple, and ash-gray, dark tones predominating; sandstone in part soft and massive, in part hard, dense, cross-bedded, and forming projecting ledges, locally conglomeratic	304
Total thickness of Chinle formation	500
Shinarump conglomerate: Hard very massive, irregularly bedded light bluish-gray to white sandstone, weathering yellowish white locally; forms prominent escarpment; at this place thickness ranges from 40 to 110 feet within a short distance, average	60
Moenkopi formation: Thin to medium-bedded ripple-marked micaceous sandstone; weathers in slopes and projecting ledges; base not exposed	250+

Section of Shinarump conglomerate and upper part of Moenkopi formation on west side of Circle Cliffs between Horse Creek and the Peaks.

[Measured by R. C. Moore.]

Shinarump conglomerate:	Feet.
Light-gray coarse-grained very massive sandstone, forming almost unbroken vertical-faced escarpment; weathers in large angular blocks	30–60
Massive cross-bedded light bluish-gray sandstone, mottled and streaked along irregular joints with purple; grades upward without demarcation into sandy limestone; weathers in single massive bed softer than overlying sandstone and therefore forming a reentrant in the cliff; upper surface uneven	16
Moenkopi formation:	
Chocolate-brown very sandy shale, grading into shaly sandstone; more calcareous above.	7
Chocolate-brown thin-bedded ripple-marked and cross-laminated sandstone	3
Chocolate-brown very micaceous sandy shale, grading into thin shaly sandstone	5
Chocolate-brown hard shaly to platy sandstone; forms slight projecting ledge	1
Brown sandy shale, grading into thin shaly sandstone; weathers as slope	8
Chocolate-brown hard platy sandstone, forming a ledge	1
Chocolate-brown sandy shale, grading into shaly sandstone	22½

Moenkopi formation—Continued.	Feet.
Chocolate-brown thin-bedded ripple-marked laminated sandstone, locally weathering massive and forming a prominent projecting ledge	5
Chocolate-brown sandy micaceous shale with thin seams and beds of soft sandstone; in upper part contains thin beds of shaly sandstone	46½
Light greenish-gray platy fine-grained micaceous sandstone, with large asymmetrical ripple marks; produces a slight bench	⅓
Chocolate-brown sandy micaceous shale, containing abundant thin beds of shaly sandstone which weathers in thin chips and platy slabs; weathers in gentle rounded slope	27
Brown very micaceous ripple-marked sandstone, with thin light-gray bands, platy with thin shale beds between harder layers; top layer very hard and slabby	2½
Chocolate-brown sandy shale, with thin yellow and brown sandstone beds that make slight benches	56
Light-yellow very massive hard sandstone; forms projecting wall	50
Light-yellow massive sandstone, weathering in thin plates; grades into shaly sandstone; forms bench	12
Chocolate-brown sandy micaceous shale	40
Light-yellow massive sandstone; locally stained red on outcrop; grades locally into shaly or thin-bedded sandstone; forms prominent bench	160
Yellow very shaly sandstone, grading to sandy shale	5
Yellow calcareous micaceous sandstone, massive but thinly laminated, with ripple bedding; grades to shaly sandstone	4
Partial thickness of Moenkopi formation	456

(Top of Kaibab limestone 25 to 40 feet below.)

Section of Moenkopi formation in canyon north of The Peaks, northwest of Wagonbox Mesa, in the Circle Cliffs.

[Measured by R. C. Moore.]

	Feet.
Shinarump conglomerate: Gray medium to fine grained massive sandstone, weathering yellowish in part, locally conglomeratic; weathers in large angular blocks; outcrop forms prominent cliff	50–150
Moenkopi formation:	
Maroon sandy shale grading into yellow shale in upper 15 feet, with many paper-thin sandstone layers	50
Yellow fine-grained soft sandstone; weathers rather shaly	3
Maroon shale with thin shaly sandstone	39
Buff, brown, and gray fine-grained sandstone, in layers 1 to 4 inches thick	8
Yellowish-brown sandy shale	26
Pink to maroon sandstone, thin bedded, with a few massive layers as thick as 16 inches at intervals; interbedded with very sandy shale; upper part yellow-brown	48
Fine-grained hard gray and light-pink sandstone, weathering brown and light gray; weathers in beds 2 to 12 inches thick, but in fresh exposures beds appear very massive; upper part more reddish than lower; ordinarily well exposed	42
Red sandstone, with thin sandy shale interbedded, medium to massive bedding	31
Very thin bedded platy light-brown and yellow to pink sandstone, weathering reddish brown; abundant ripple marks; grades locally into shale; forms slopes	36
Pink to red sandy shale, containing thin beds of platy sandstone; weathers in slopes	21
Total thickness of Moenkopi formation	304
Kaibab limestone: Deep-yellow to buff very hard fine-grained dense dolomitic limestone, in massive beds 3 to 6 feet thick; weathers in large angular blocks; forms prominent bench; exposed thickness	20

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A NEW FAUNA FROM THE COLORADO GROUP OF SOUTHERN MONTANA

BY

JOHN B. REESIDE, JR.

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A NEW FAUNA FROM THE COLORADO GROUP OF SOUTHERN MONTANA.

By JOHN B. REESIDE, Jr.

INTRODUCTION.

This paper describes a small but interesting fauna collected in 1921 by W. T. Thom, jr., Gail F. Moulton, T. W. Stanton, and K. C. Heald in the Crow Indian Reservation in southern Montana. The locality is in sec. 36, T. 6 S., R. 32 E., Big Horn County, and is 2 miles east of the Soap Creek oil field.

The stratigraphic section in the Soap Creek oil field was described briefly by Thom and Moulton in a press notice issued by the United States Geological Survey December 5, 1921, entitled "The Soap Creek oil field, Crow Indian Reservation, Mont." It was described also in a later and more general paper.[1] The youngest beds present near the oil field belong to the Niobrara formation, but in the adjacent parts of the Crow Reservation to the east and north higher formations are present and are in part included in the section given below. The part of the section from the Cloverly formation to the Niobrara formation, inclusive, is derived from the publications mentioned above and from data kindly supplied by Mr. Thom. The thicknesses given for the Eagle sandstone and the Telegraph Creek formation apply especially to the vicinity of Pryor Creek, some 30 miles north of the Soap Creek oil field. The included lists of fossils are based on the writer's determinations.

Partial section of formations exposed in the Crow Indian Reservation, Mont.

Feet.

Eagle sandstone................................ 200–250

Sandstones and some shales; at base the massive Virgelle sandstone member. This formation contains *Scaphites hippocrepis* (Dekay), *Scaphites* n. sp. aff. *S. aquisgranensis* Schlueter, *Inoceramus* aff. *I. lobatus* Goldfuss, *Placenticeras syrtale* (Morton), *Placenticeras meeki* Boehm, *Placenticeras planum* Hyatt, *Baculites ovatus* Say, *Baculites asper* Morton, *Baculites* n. sp. aff. *B. anceps* Lamarck, and many other fossils.

Feet.

Telegraph Creek formation...................... 320–350

Sandstones and shales. This group of beds contains at places in the upper part a fauna like that of the Eagle sandstone, but in the lower beds it contains *Uintacrinus* sp., *Marsupites* sp. (identified by Frank Springer), *Inoceramus deformis* Meek var., *Ostrea* cf. *O. congesta* Conrad, *Baculites* sp., *Puzosia* (*Latidorsella*) n. sp., and *Scaphites* n. sp. aff. *S. geinitzi* D'Orbigny.

Niobrara formation (top formation of Colorado group).. 400

Bluish calcareous shale in upper and lower parts; dark shale in middle. In the upper part it contains *Uintacrinus socialis* Grinnell (identified by Frank Springer), *Yoldia* sp., *Inoceramus*, large thick-shelled species, *Ostrea congesta* Conrad, *Lunatia concinna* (Hall and Meek), *Tessarolax* cf. *T. hitzi* White, *Baculites* sp., *Scaphites vermiformis* Meek and Hayden, and fish scales. In the middle part it contains *Inoceramus* aff. *I. lamarcki* Parkinson, *Inoceramus umbonatus* Meek and Hayden, *Inoceramus*, large thick-shelled species, *Pteria* aff. *P. nebrascensis* (Evans and Shumard), *Anatina* aff. *A. subgracilis* (Whitfield), *Veniella goniophora* Meek, *Cardium* n. sp., *Fusus* sp., *Volutoderma* sp., *Baculites* aff. *B. anceps* Lamarck, *Baculites asper* Morton, *Scaphites vermiformis* Meek and Hayden. In the lower part it contains *Inoceramus*, large thick-shelled species, *Ostrea congesta* Conrad, and the basal bed, a zone of large yellow concretions, contains *Yoldia* sp., *Nemodon* sp., *Barbatia* n. sp., *Inoceramus fragilis* (Hall and Meek)?, *Inoceramus* (*Actinoceramus*) n. sp., *Veniella goniophora* Meek, *Callista tenuis* (Hall and Meek), *Corbula* cf. *C. nematophora* Meek, *Dentalium* sp., *Gyrodes* aff. *G. petrosa* (Morton), *Turritella* aff. *T. whitei* Stanton, *Anchura* sp., *Nautilus* sp., *Baculites* sp., and *Scaphites vermiformis* Meek and Hayden.

Carlile shale.................................... 425

This formation may be divided into a number of units as follows:.

Dark shale with whitish septarian nodules containing *Inoceramus labiatus* (Schlotheim), *Veniella goniophora* Meek, *Corbula* aff. *C. nematophora* Meek, *Pseudomelania?* sp., *Fusus* sp., *Prionocyclus wyomingensis* Meek. Thickness 50 feet.

Zone of large yellowish sandstone concretions. Thickness 5 feet.

Dark shale. Thickness 35 feet.

Shale with thin hard rusty red concretions and layers containing *Inoceramus fragilis* Hall and

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[1] Thom, W. T., jr., Oil and gas prospects in and near the Crow Indian Reservation, Mont.: U. S. Geol. Survey Bull. 736, pp. 35-53, 1922 (Bull. 736-B).

Feet.

Meek, *Inoceramus* cf. *I. lamarcki* Parkinson, *Veniella* sp., *Volutoderma?* sp., *Baculites gracilis* Shumard, *Scaphites warreni* Meek and Hayden, *Prionotropis* aff. *P. woolgari* (Mantell). Thickness 30 feet.

Dark shale. Thickness 60 feet.

Bluish calcareous shale containing in its lower part the fauna described in this paper. Thickness 100 feet.

Dark shale and bentonite. Thickness 145 feet.

Frontier formation.............................. 410

Chiefly dark shale with bentonite but with a zone of thin coarse sandstones near the top. Shark teeth the only fossils observed.

Mowry shale.............................. 200–300

Hard bluish-white shale with layers of hard dark shale. Contains abundant fish remains but few other fossils.

Thermopolis shale.............................. 550–800

Dark marine shale with streaks and lenses of light-colored sandstone containing *Inoceramus labiatus* (Schlotheim), *Pteria* aff. *P. nebrascensis* (Meek and Hayden), *Ostrea* sp., *Entolium* sp., *Modiola* n. sp., *Gyrodes* aff. *G. depressa* Meek, fish and turtle remains. Middle part of formation of dark clay and bentonite; lower part of dark marine shale.

Cloverly formation.............................. 320–425

An upper member of sandy shale and thin-bedded rusty sandstone that may represent the Dakota sandstone of Upper Cretaceous age.

A middle member consisting of variegated shale where exposed along the Big Horn Mountains and containing *Unio* sp. and *Viviparus?* sp. and a basal member of thick coarse-grained conglomeratic sandstone. These divisions may represent the Fuson shale and Lakota sandstone, of Lower Cretaceous age.

THE FAUNA AND ITS RELATIONS.

The collection described in this paper contains five species of ammonites referred to three genera, two species of *Inoceramus*, an ostreid, and a gastropod.

The species are as follows:

Vascoceras thomi Reeside, n. sp.
Vascoceras moultoni Reeside, n. sp.
Vascoceras stantoni Reeside, n. sp.
Vascoceras sp. undeterminable.
Pseudotissotia (Choffaticeras) sp.?
Helicoceras pariense White?
Inoceramus labiatus (Schlotheim).
Inoceramus sp. undetermined.
Ostrea or Exogyra sp.
Gastropod, undetermined.

This fauna is known from only this one locality in the Western Interior province of North America, and consequently its correlation must rest in large part on its position with relation to other faunal zones in the same stratigraphic section and in the adjacent region. It is therefore of interest to consider some of the faunal zones recognizable in the Cretaceous deposits of this province.

A series of more or less widespread and more or less distinctly defined faunal zones have long been recognized in the Cretaceous deposits of the Western Interior. The lowest zone to be considered here is well characterized only in the southern part of the province, where it contains *Exogyra columbella* Meek and *Gryphaea newberryi* Stanton as its guide fossils. This zone includes the Graneros shale of the central Great Plains, the basal part of the Mancos shale of New Mexico, Colorado, and Utah, and the Thermopolis shale of the north. At many places, especially in the north, it is nearly barren of fossils, and those present are not sufficiently restricted to serve as guide fossils.

Above this zone occurs a zone with an abundance of *Inoceramus labiatus* (Schlotheim). In the central Great Plains region this zone is contained in the Greenhorn limestone, and very few other fossils than the guide fossil have been found in it. In western Colorado and the adjacent region it is well marked in the lower part of the Mancos shale. It occurs in southern and central Wyoming in the Frontier formation and in northern Montana in the lower part of the Colorado shale.

Above this zone of *Inoceramus labiatus* lies a zone which contains as its more prominent and restricted species *Scaphites warreni* Meek and Hayden, several species each of *Prionotropis*, and *Prionocyclus*, *Inoceramus fragilis* Hall and Meek, *Inoceramus dimidius* White, and *Ostrea lugubris* Conrad. It very rarely contains *Inoceramus labiatus* (Schlotheim). This zone is perhaps the most sharply defined and most widely recognized of the series. It comprises the entire Carlile shale of the central Great Plains and Black Hills regions, part of the Mancos shale of western Colorado and adjacent regions, the Carlile shale of Wyoming, and part of the Colorado formation of Montana.

Above the zone of *Scaphites warreni* comes a zone which contains *Uintacrinus socialis* Grinnell, *Inoceramus umbonatus* Meek and Hayden, *Inoceramus deformis* Meek, and, especially in the north, *Scaphites ventricosus* Meek and Hayden and *Scaphites vermiformis* Meek and Hayden. A very abundant and locally restricted form of this zone is *Ostrea congesta*

Conrad. *Inoceramus labiatus* is reported in the literature as occurring here also, but it has not been found in numerous recent collections, and its earlier assignment to the fauna of this zone is very probably due to the erroneous reference of local exposures of the Greenhorn limestone to the Niobrara formation in Nebraska, Kansas, and elsewhere prior to Darton's work in that region. In this zone falls the Niobrara formation of the Great Plains region, part of the Mancos shale of western Colorado and the adjacent regions, the Niobrara formation of Wyoming, and the upper part of the Colorado shale of northern Montana.

Above this zone of *Uintacrinus* and *Scaphites vermiformis* comes a zone containing *Scaphites hippocrepis* (DeKay), *Scaphites* n. sp. aff. *S. aquisgranensis* Schlueter, *Placenticeras syrtale* (Morton) and its allies, *Placenticeras planum* Hyatt, and *Inoceramus* aff. *I. lobatus* Goldfuss. In New Mexico this zone has yielded also *Mortoniceras* aff. *M. delawarense* (Morton). In Montana and in southwestern Colorado and adjacent parts of New Mexico there is a subzone at the base of this zone which lacks *Scaphites hippocrepis* and *Scaphites* aff. *S. aquisgranensis* but which contains *Scaphites* n. sp. aff. *S. geinitzi* D'Orbigny as its most distinctive form. The zone of *Scaphites hippocrepis* is represented by the Eagle sandstone and Telegraph Creek formation of southern Montana, part of the Cody shale of northern Wyoming, part of the Steele shale of central and southern Wyoming, and the upper part of the Mancos shale of southwestern Colorado and adjacent New Mexico. Presumably the basal part of the Pierre shale of the central Great Plains and Black Hills regions represents this zone, though the distinctive species have not been found in it except in northeastern New Mexico. Above the zone of *Scaphites hippocrepis* other faunal zones may be recognized but will not be described in this paper.

The stratigraphic section at the Soap Creek oil field and in the adjacent country, as shown in the section given on page 25, has afforded enough paleontologic data to determine the relative position of the fossils described in this paper. The beds containing the fauna include the highest bed in which *Inoceramus labiatus* occurs abundantly and lie immediately beneath beds with the characteristic fauna of the zone of *Scaphites warreni*. They are therefore to be correlated with at least the upper part of the Greenhorn limestone of the central Great Plains, though the occurrence of *Inoceramus labiatus* in beds some 800 feet lower in the section raises a doubt whether the beds containing *Vascoceras* represent all of the Greenhorn limestone as developed at such localities as those in eastern Colorado, where the Greenhorn limestone contains the only beds in which *Inoceramus labiatus* occurs, is only about 50 feet thick, and is separated from the Dakota sandstone by scarcely 200 feet of Graneros shale. It is possible that the relatively great thickness of Graneros shale present in the Black Hills region beneath the Greenhorn limestone is due entirely to greater deposition of material to form the shale without an appreciably greater lapse of time and that the Greenhorn limestone, which does not change much in thickness over the whole region, represents approximately the same time interval everywhere. If so, the beds containing *Vascoceras* may represent all the time interval of the Greenhorn limestone and its equivalents in various parts of the Western Interior. In central Montana the Mosby sandstone member of the Warm Spring shale[2] occupies a position in the section similar to that of the beds containing *Vascoceras*. Inasmuch as the faunas of the two units have in common only *Inoceramus labiatus* they do not help in determining the relations between them. Perhaps the only suggestion offered is the occurrence of *Metoicoceras whitei* Hyatt in the Mosby sandstone. This species is most abundant in and most characteristic of the lower part of the Colorado group in southern Utah and in New Mexico and may indicate that the conditions which permitted the northward extension of *Vascoceras* as far as southern Montana were the same as those which permitted *Metoicoceras* to reach central Montana and that the Mosby sandstone and the beds containing *Vascoceras* represent the same time.

The only other occurrence of *Vascoceras* in North America is that at Cerro del Macho, in the State of Coahuila, Mexico, described by Böse.[3] Here the associated fossils are more numerous, though none of the species seem to be identical with those from Montana, except *Inoceramus labiatus*. Böse has given a good summary of the distribution of the *Vascoceras* fauna and of its composition in all its principal occurrences. The fauna in its fullest and most typical development contains species of the ammonite genera *Fagesia, Vascoceras, Mammites, Pseudaspidoceras, Neolobites, Pseudotissotia, Hoplitoides*, and *Thomasites*. It is the Salmurian fauna of the European geologists and is widely distributed in the Mediterranean region. It occurs in the lower and middle Turonian of Portugal; the lower Turonian of Algeria, Tunis, and Egypt; the Turonian of the southern Sahara region; and in Brazil, Colombia, Peru, and Mexico. Faunas more or less related though not yet reported to contain *Vascoceras* occur in the Turonian of southern France, in India, and in Japan.

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[2] U. S. Geol. Survey Bull. 736, p. 172, 1922 (Bull. 736–F).

[3] Böse, Emil, On a new ammonite fauna of the lower Turonian of Mexico: Texas Univ. Bull. 1856, pp. 173–257, 1918.

A comparison of the faunal succession in the Western Interior province with that in western Europe suggests the following correlations:

Western Interior.	Europe.
Zone of *Scaphites hippocrepis*........	Lower Campanian. Upper Santonian.
Zone of *Uintacrinus, Inoceramus umbonatus*, and *Scaphites vermiformis*.	Lower Santonian. Coniacian.
Zone of *Scaphites warreni*............	Upper Turonian.
Zone of *Inoceramus labiatus* (*Vascoceras* at top in Montana)..........	Lower Turonian.

Apparently the present occurrence of *Vascoceras* would agree with the accepted assignment of the other known occurrences to the lower Turonian. It might be middle Turonian, if such a unit were recognized, but scarcely younger.

DESCRIPTIONS OF SPECIES.

Genus VASCOCERAS Choffat.

Choffat's original description[4] is in part as follows:

> Genus formed by shells more or less thick, sometimes globular, with ventral region rounded, ornamented in youth by ribs giving rise to tubercles on the flanks and to tubercles or elongated swellings on each side of the siphon. With some rare exceptions (*Vascoceras subconciliatum*), these lines of tubercles disappear in the adult stage, those of the umbilical border persisting longer, and the ventral region, or even all the visible part of the shell, is without ornamentation.
>
> The length of the living chamber is from one-half to three-fourths of a whorl.
>
> The suture shows two broad, rounded, weakly incised saddles, the third saddle much less important than it would be if the decrease were regular. The lobes are broad and divided by small saddles, in general not incised. From the position of these saddles the first lobe may be considered as divided into two or three parts. The second lobe is either simple or divided into two. [Translated.]

Choffat proposed four sections of the genus—(*a*) monotuberculate forms with wide umbilicus, (*b*) subglobular forms with rounded umbilical border, (*c*) globular forms with angular or subangular umbilical border, (*d*) multituberculate forms.

Pervinquière[5] later discussed *Vascoceras*, modifying somewhat Choffat's original description. Pervinquière's description is as follows:

> Shell more or less thick, sometimes globular, with ventral region rounded, ornamented, in youth, by ribs bearing umbilical tubercles and marginal tubercles; these tubercles become less distinct in the adult stage (the umbilical tubercles remain distinct longer) and even disappear completely except on one group. There is never a median ventral tubercle. Living chamber measuring three-fourths of a whorl or even more. * * * Suture including two broad, rounded, little incised saddles; the third much smaller. Lobes broad and divided by small unincised saddles. [Translated.]

Pervinquière recognizes only three sections of the genus:

> 1. Group of *V. gamai* and of *V. douvillei-durandi*. Monotuberculate forms with wide umbilicus in the first species and more restricted in the second. There is every intermediate form between the two, as regards both general form and the greater or lesser rounding of the umbilical shoulder.
> 2. Group of *V. harttiformis*. Globular forms, with the umbilicus generally narrow, the umbilical shoulder more or less angular.
> 3. Group of *V. subconciliatum*. Multituberculate forms, departing notably from the preceding and approaching *Mammites* and the extreme forms of *Acanthoceras*.

Pervinquière points out that *Vascoceras* differs from the nearly related genus *Fagesia* Pervinquière in general form, in the much earlier disappearance of the ribs and tubercles, and especially in the suture. The suture of *Fagesia* has four slender lateral saddles, rounded in the upper part and trifid in subdivision; three lateral lobes, of which the first is profoundly bifid, the second less so, and the third pointed. Pervinquière adds, however, that some forms of *Vascoceras* are difficult to distinguish from *Fagesia*.

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[4] Choffat, Paul, Les ammonées du Bellasien, des couches à *Neolobites vibrayeanus*, du Turonien, et du Sénonien: Faune crétacique du Portugal, vol. 1, ser. 2, p. 53, 1898.

[5] Pervinquière, Léon, Études de paléontologie tunisienne, pt. 1, Céphalopodes des terrains secondaires, pp. 331–332, 1907.

The specimens in hand from Montana are a bit confusing in their relations. The general form, except perhaps for the width of the umbilicus, would permit an assignment to *Fagesia*, and the proportions and degree of incision of the suture fit those of *Fagesia* better than those of *Vascoceras*. Moreover, the umbilical tubercles are prominent, and there are traces of the ventral ribs in even the largest specimens. The younger whorls, however, show distinctly the umbilical and ventral tubercles of *Vascoceras*, the umbilicus is wider than shown in most of the figured specimens of *Fagesia*, and the suture in every specimen examined shows a pointed first and second lateral lobe, not bifid. The writer therefore assigns the specimens to *Vascoceras* rather than to *Fagesia* and further would place the first two of the species here described under Pervinquière's section 1 and the third under section 2.

Vascoceras thomi Reeside n. sp.

Plate XI, figures 1-2; Plate XII, figures 1-2; Plate XIII, figures 1-2; Plate XIV, figures 1-2; Plate XV, figures 1-7; Plate XVI, figures 1-6.

Shell stout, coronate. Earlier whorls not well shown in the type specimen except for the umbilical part, but apparently stout. Whorls above 115-millimeter diameter have a moderately depressed, oval cross section. Living chamber in type occupies three-fourths of a whorl and is apparently incomplete. Maximum diameter of type 165 millimeters. Umbilicus deep but fairly wide—about one-half the diameter of the shell in width. Umbilical shoulders rounded but well defined.

Sculpture of earlier whorls of type specimen seen only in the umbilicus, where it consists of large blunt conical nodes, seven to the whorl. On the last whorl of the type faint coarse ribs connect the umbilical nodes and a faint flattening on the venter seems to correspond to the space between the marginal nodes of the younger stages.

The suture shows a fairly broad ventral lobe and four lateral lobes and saddles, only moderately incised. The first lateral lobe is bluntly pointed, and the first lateral saddle is trifid.

A very large specimen (see Pl. XIII, figs. 1-2; Pl. XIV, figs. 1-2) assigned to this species has a maximum diameter of 260 millimeters and is apparently almost complete. The inner whorls are poorly preserved. The living chamber occupies three-fourths of a whorl; the aperture is not preserved. The suture of this specimen has wider saddles than those of the suture of the type but is otherwise like it. The umbilical nodes and obscure ventral ribs persist to the end of the specimen.

A small specimen assigned to this species (see Pl. XV, figs. 1-7) shows the sculpture and form of the stages following that at the diameter of 25 millimeters. The whorls to a diameter of about 40 millimeters are as high as wide and have strong rounded ribs that begin at the umbilical nodes, pass with a slight forward curve to the margin of the venter, where they form an elongated, poorly defined node, and then continue unbroken across the venter. Two or three ribs start from each umbilical node, and there are some intercalated ribs. On the half whorl from the diameter of 25 millimeters to the diameter of 40 millimeters there are four umbilical nodes and 15 ventral ribs. Above the diameter of 40 millimeters the ribs are less and less distinct on the venter, and at the diameter of 75 millimeters there are only indistinct folds. The umbilical nodes, however, remain large and blunt. The suture is much like that of the type.

A fourth specimen (see Pl. XVI, figs. 1-6), about the size of that just described, is assigned with some doubt to this species. The sculpture is much weaker than on the specimen just described and less than one would expect to find on the type at the same size. The cross section of the whorl is somewhat more depressed, and the suture is more incised. The specimen is closer to *V. thomi* than to the other species described in this paper and is therefore attached to it.

Vascoceras thomi may be recognized by its well-rounded venter and relatively high whorls. It differs from *V. moultoni* Reeside in possessing more elevated whorls and in sutural details; from *V. stantoni* Reeside in its much more elevated whorls and less angular umbilical shoulder It suggests somewhat *V. silvanense* Choffat [6] but is apparently a much larger species and has a wider umbilicus and a different suture. It also suggests *V. adonense* Choffat [7] but differs in the retention of the tubercles, in the form of the umbilicus, and in suture.

---

[6] Choffat, Paul, Les ammonées du Bellasien, des couches à *Neolobite vibrayeanus* du Turonien, et du Sénonien: Faune crétacique du Portugal, vol. 1, ser. 2, p. 57, pl. 8, fig. 5; pl. 21, fig. 9, 1898.

[7] Idem, p. 59, pl. fig. 9, 3; pl. 21, fig. 12.

Vascoceras moultoni Reeside, n. sp.

Plate XVII, figures 1-2; Plate XVIII, figures 1-2.

Shell stout, coronate. Earliest stage seen in the single specimen available is at diameter of 80 millimeters. Whorl has broad, depressed-oval cross section. Width of umbilicus more than half the diameter of the shell. Umbilical shoulder bluntly rounded. Living chamber and aperture unknown.

Sculpture of the visible whorls consists chiefly of large blunt conical nodes on the umbilical shoulders; umbilical wall smooth; venter smooth except for ill-defined broad, low ribs connecting the nodes.

Suture little incised; the lobes long and slender, the saddles rather broad and open; first lateral lobe pointed; first lateral saddle trifid.

Vascoceras moultoni may be recognized by the depressed-oval form of the cross section of the whorl and the relatively simple suture. It has a broader, more depressed whorl and simpler suture than *V. thomi* Reeside and a rounded rather than a subangular umbilical shoulder as in *V. stantoni* Reeside. It resembles some of the forms assigned in the literature to *V. douvillei* Choffat but is distinct from all of them in the persistence of the umbilical tubercles and in the suture.

Vascoceras stantoni Reeside, n. sp.

Plate XIX, figures 1-2; Plate XX, figures 1-3; Plate XXI, figures 1-3.

Shell stout, coronate. Earliest stage seen, at diameter of 35 millimeters, has whorl with depressed-ovate cross section. The form of the cross section changes little to the stage at diameter of 100 millimeters but thereafter becomes a broad pentagon. Width of umbilicus about half the diameter of the shell; umbilical shoulders subangular. Type entirely septate.

Sculpture of the whorl at diameter of 35 millimeters consists of coarse rounded ribs starting in pairs from a high conical umbilical node, passing to the margin of the venter, where they form blunt elongated nodes, and then continuing unbroken across the venter. There are four umbilical nodes and perhaps 10 ventral ribs on the half whorl succeeding the diameter of 35 millimeters. At the diameter of 70 millimeters, a whorl later, the whorl is smooth except for the umbilical nodes, and it remains so in all the later stages seen.

The suture shows four lateral lobes and saddles, moderately incised. The first lateral lobe is pointed, and the first lateral saddle trifid.

Two other specimens assigned to this species show a much later stage of growth than the type. The better preserved though less complete specimen (see Pl. XXI, figs. 1-3) would have measured about 275 millimeters in diameter. It has the same form of the whorl as the type and preserves even at so late a stage the umbilical tubercles and traces of the ventral ribs. The suture of this specimen was not seen.

Vascoceras stantoni may be recognized by its broad whorls with depressed pentagonal cross section and subangular umbilical shoulders. In the early stages it is not greatly different from *V. thomi* Reeside except that the ribs are finer, but in the later stages it departs sharply from that species in the form of the whorl. It differs from *V. moultoni* Reeside in its subangular umbilical shoulders and in sutural details. It is perhaps closest to *V. harttiformis* Choffat[8] in its general form but differs in the persistence of the umbilical nodes, in the greater width of the umbilicus, and in the suture.

Vascoceras sp.

Plate XX, figure 4.

The young stages of these American species of *Vascoceras* seem to be missing in most of the specimens in hand. One rather poorly preserved mold shows the exterior of younger whorls than any of the other specimens and is therefore figured.

Genus PSEUDOTISSOTIA Peron.

Subgenus CHOFFATICERAS Hyatt.

Pseudotissotia (Choffaticeras) sp.?

Plate XII, figures 3-6.

A single small specimen of an ammonite with sharp venter was obtained in cleaning the umbilicus of one of the large specimens of *Vascoceras*. This small specimen is nearly complete, preserving three-fourths of the last whorl unseptate, although only 13 millimeters in greatest diameter. The shell is very much compressed, discoid. The flanks of the whorls curve evenly from the umbilicus to the ventral keel. The umbilicus is moderately wide, about one-fourth the diameter of the shell, and the umbilical margin is rounded. The entire shell is smooth, without any trace of ribs or nodes. The suture is well preserved and very simple. It shows a very broad ventral lobe, a broad first lateral saddle with two incipient marginal lobes, a broad first lateral lobe with a suggestion of an incipient marginal lobe on the outer side, a simple second lateral saddle and lobe, and one auxiliary saddle and lobe.

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[8] Choffat, Paul, op. cit., p. 53, pl. 12, fig. 3; pl. 13, figs. 3-6; pl. 21, figs. 22-24, 1898.

The generic assignment of this little ammonite is uncertain. On the basis of Hyatt's figures of the sutures of young *Metengonoceras* and *Coelopoceras*[9] it could scarcely belong to those genera of sharp-ventered ammonites, both of which are known to occur in the Colorado group of the Interior province of North America. Of other genera its suture appears to be proportioned more like that of *Pseudotissotia* than of any other genus, and it is therefore tentatively assigned to *Pseudotissotia* and to the subgenus *Choffaticeras* because it shows no trace of ventrolateral keels or nodes.

Helicoceras pariense White?

Plate XX, figures 5-6.

A single fragment of a small cephalopod that appears to have had an open coil in a single plane was uncovered in preparing the type of *Vascoceras thomi*. It suggests very strongly young *Helicoceras pariense* White,[10] though the specimen is insufficient to warrant an unquestioned assignment to that species. The suture is not visible, but the form and sculpture agree closely with those of the specimen figured by Stanton.

Hyatt[11] referred *Helicoceras pariense* White to his genus *Exiteloceras*, but the writer prefers to use the more general name here.

Inoceramus labiatus (Schlotheim).

Plate XIV, figures 3-5.

A number of specimens of this widespread species accompany the other fossils of the collection. They are mostly of small size but do not depart in any way from typical shells from other localities.

Inoceramus sp.

Plate XIV, figure 6.

A single small specimen of a relatively coarse-ribbed, transversely elongated species of *Inoceramus* is contained in the collection. It resembles in some respects several different species but is hardly sufficient for certain identification.

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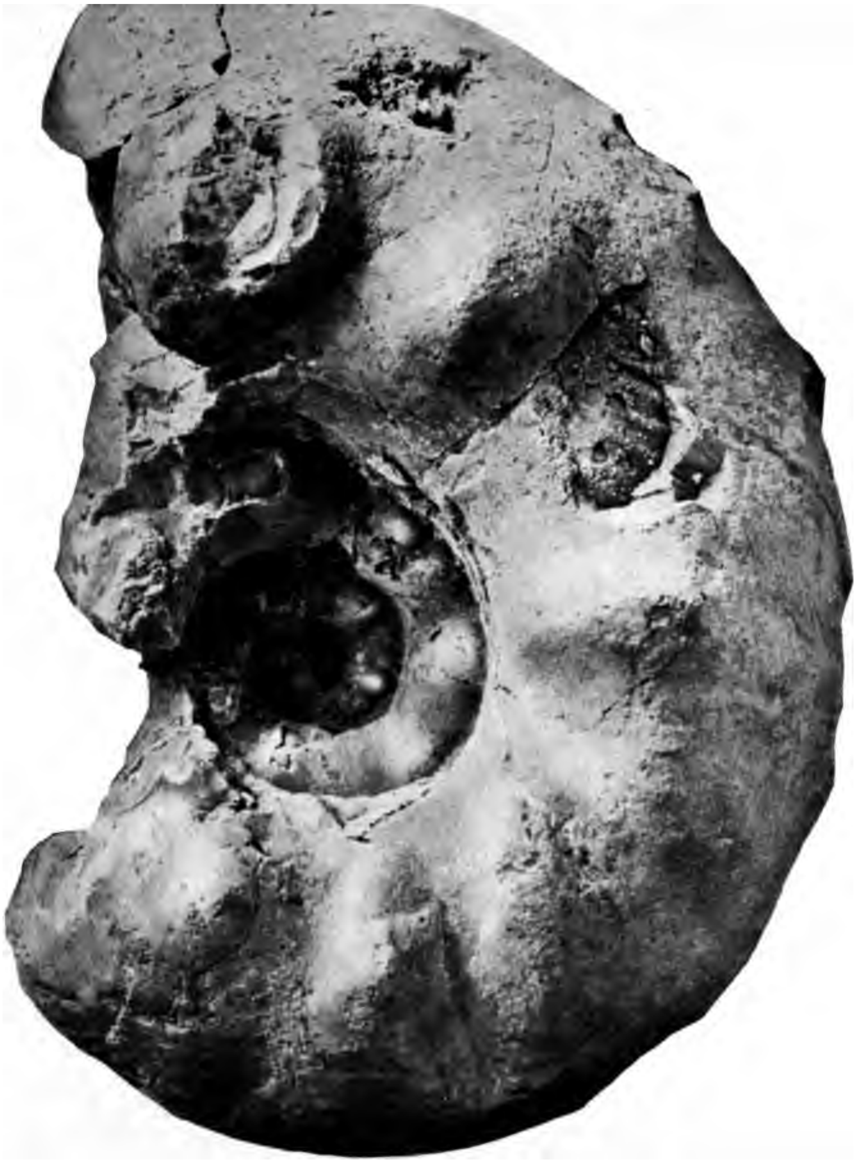
[9] Hyatt, Alpheus, Pseudoceratites of the Cretaceous: U. S. Geol. Survey Mon. 44, pl. 10, figs. 10-12; pl. 27, fig. 13, 1903.

[10] Stanton, T. W., The Colorado formation and its invertebrate fauna: U. S. Geol. Survey Bull. 106, p. 164, pl. 35, figs. 2-4, 1893.

[11] Hyatt, Alpheus, The phylogeny of an acquired characteristic: Am. Philos. Soc. Proc., vol. 32, p. 577, 1894.

PLATES XI-XXI.



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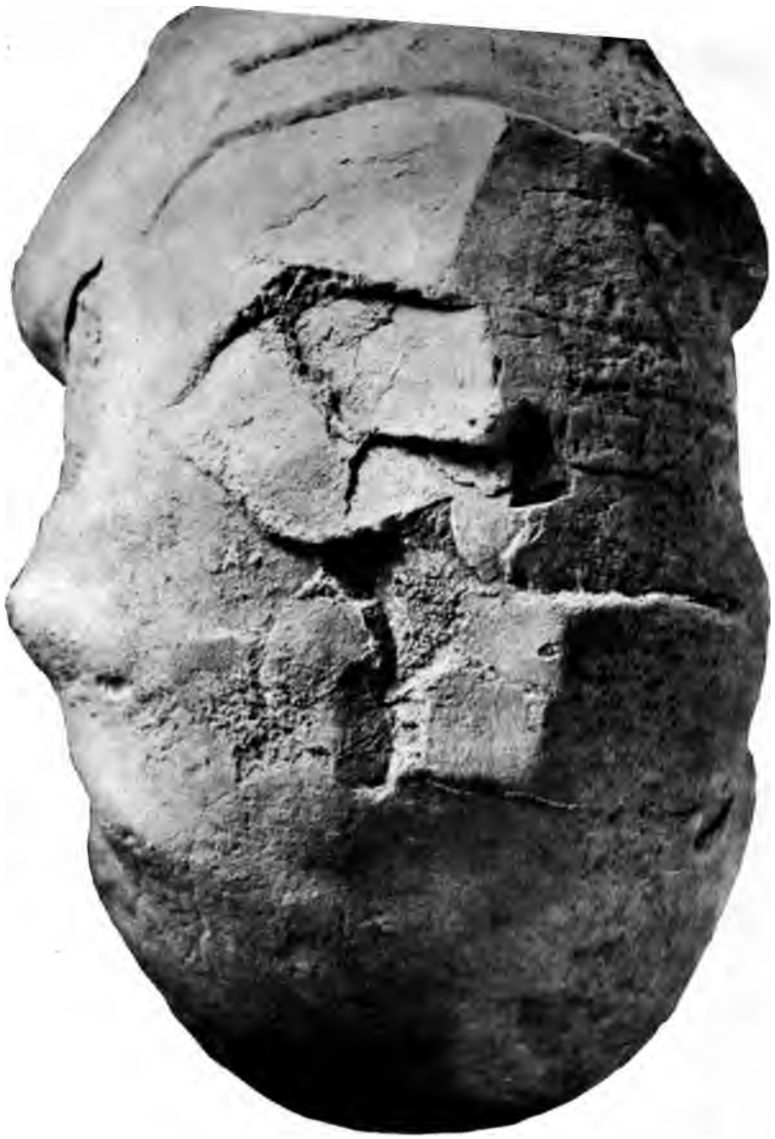
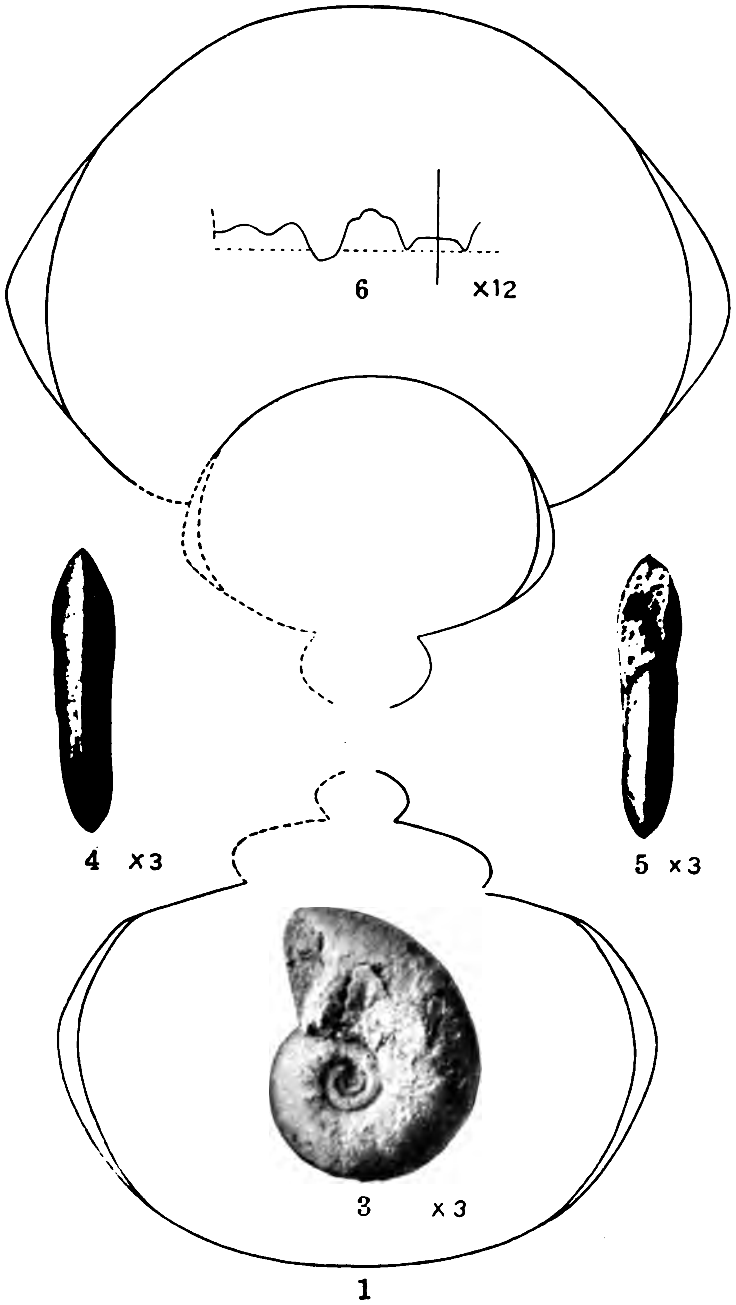
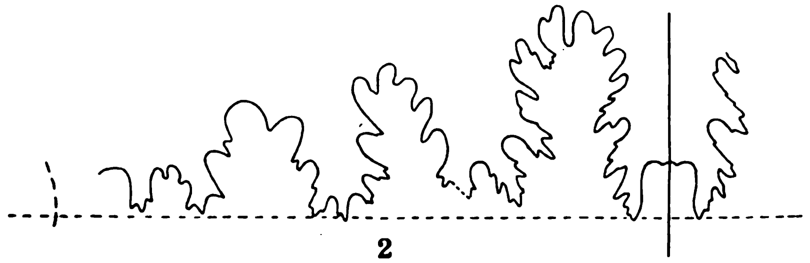


2

FOSSILS FROM THE COLORADO GROUP OF SOUTHERN MONTANA.

Vascoceras thomi Reeside, n. sp. Type specimen (U. S. Nat. Mus. catalog No. 32535). 1, Side view; 2, rear view.

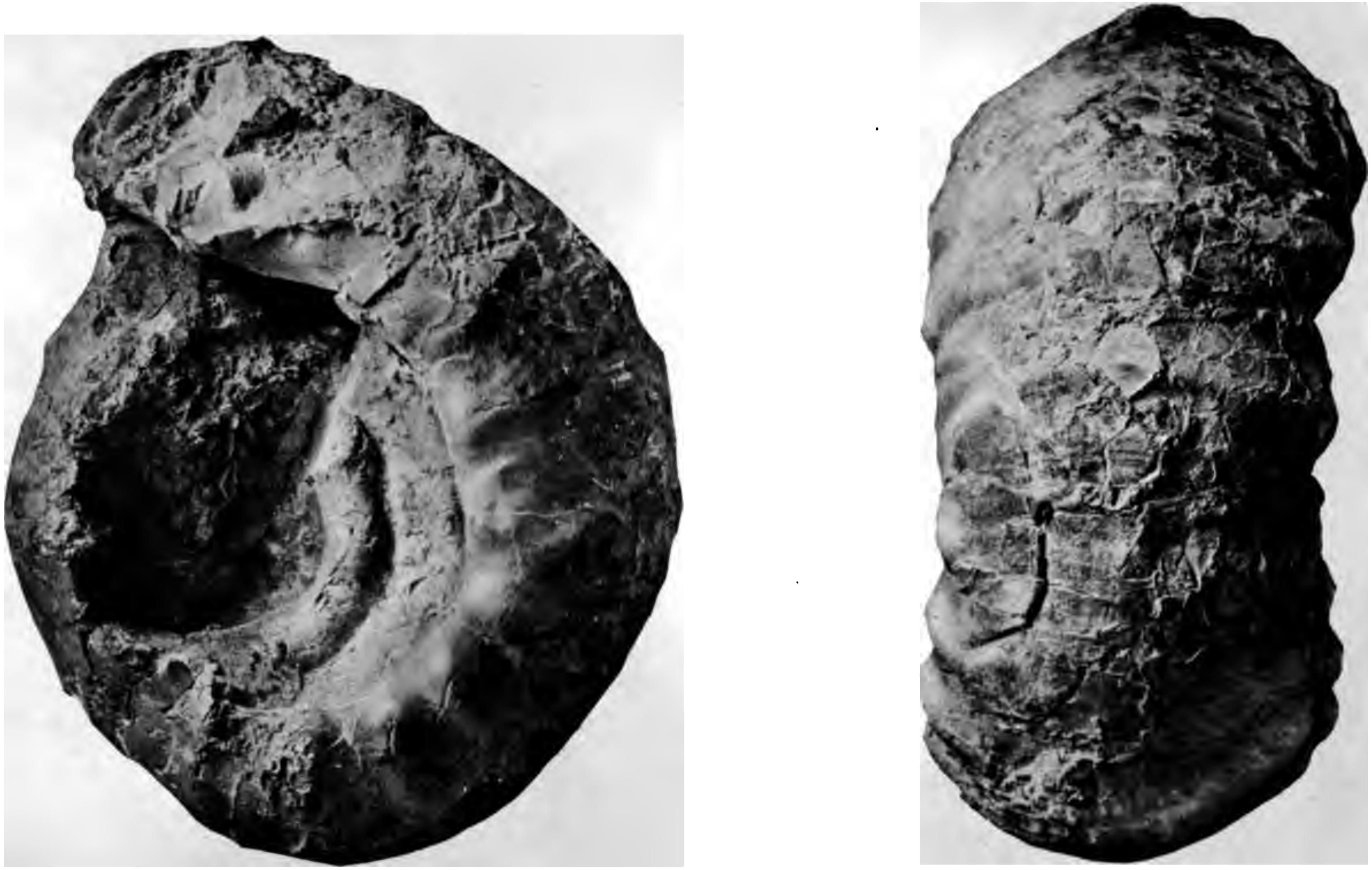




FOSSILS FROM THE COLORADO GROUP OF SOUTHERN MONTANA.

1–2. *Vascoceras thomi* Reeside, n. sp. Type specimen (U. S. Nat. Mus. catalog No. 32535). **1,** Cross section at diameter of 165 **2,** suture at diameter of 100 millimeters.

3–6. *Pseudotissotia* (*Choffaticeras*) sp.? **3,** Side view; **4,** rear view; **5,** front view; **6,** suture. (U. S. Nat. Mus. catalog No. 32541.



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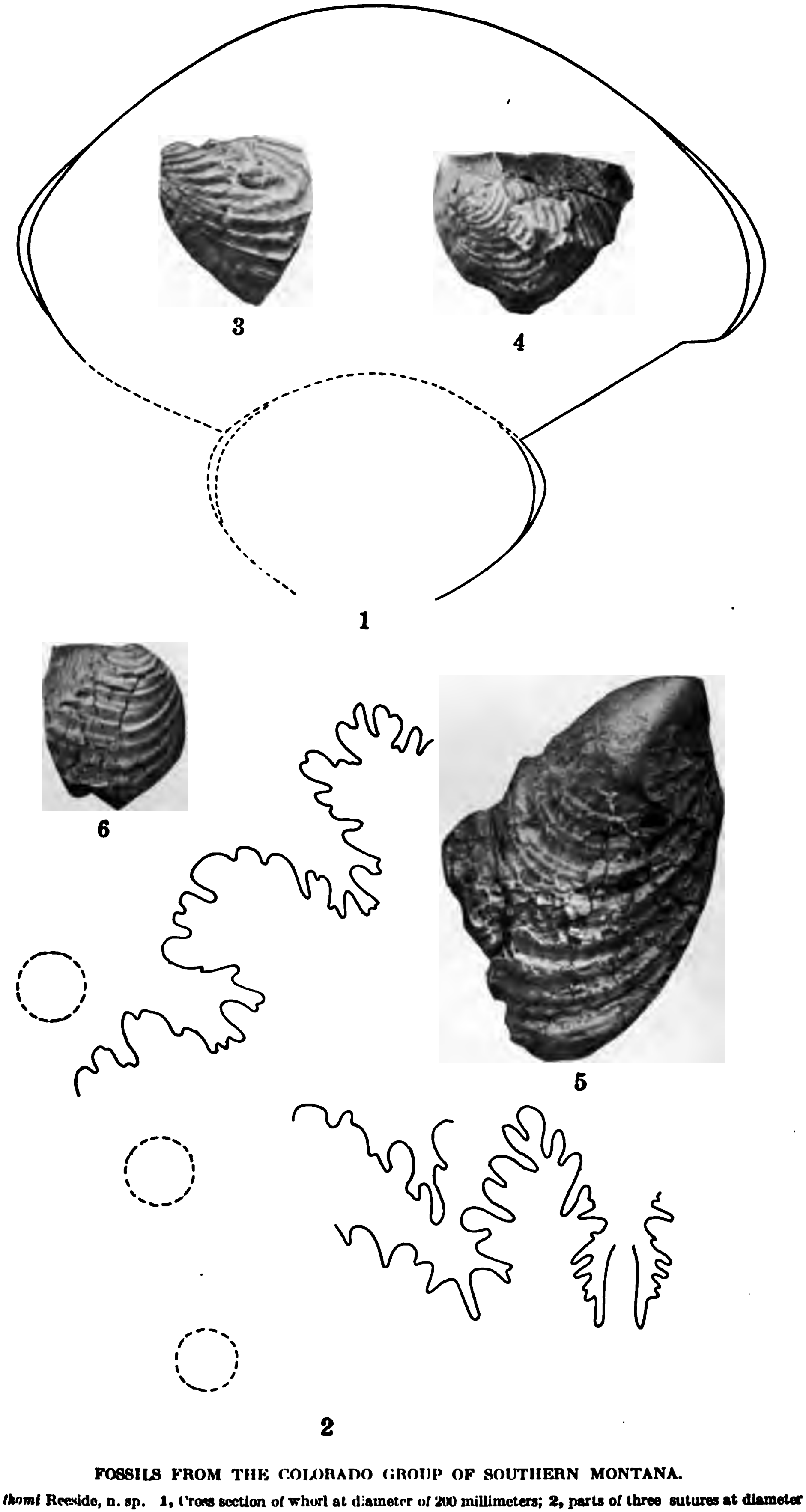
FOSSILS FROM THE COLORADO GROUP OF SOUTHERN MONTANA.

Vascoceras thomi Reeside, n. sp. 1, Side view; 2, rear view. (U. S. Nat. Mus. catalog No. 32536.)

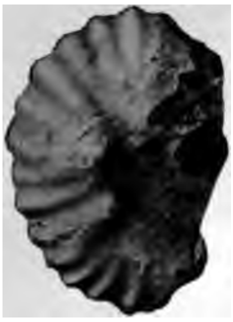


FOSSILS FROM THE COLORADO GROUP OF SOUTHERN MONTANA.

1-2. ***Vascoceras thomi*** Reeside, n. sp. **1,** Cross section of whorl at diameter of 200 millimeters; **2,** parts of three sutures at diameter of 150 millimeters of specimen shown on Plate XIII. (U. S. Nat. Mus. catalog No. 32536.)

3-5. ***Inoceramus labiatus*** (Schlotheim). (U. S. Nat. Mus. catalog Nos. 32540 and 32543.)

6. ***Inoceramus*** sp. (U. S. Nat. Mus. catalog No. 32542.)



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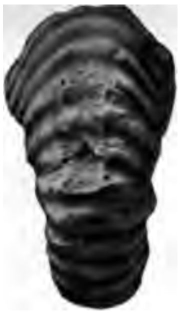

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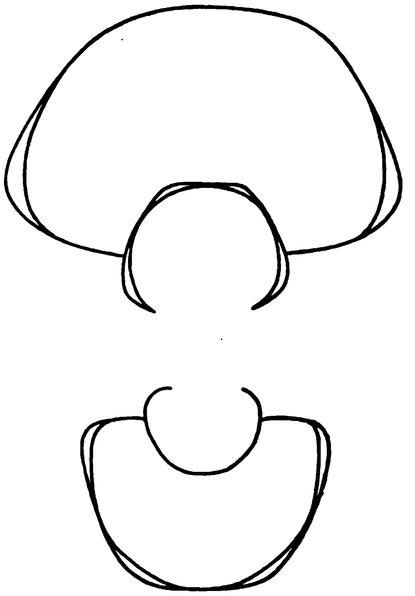

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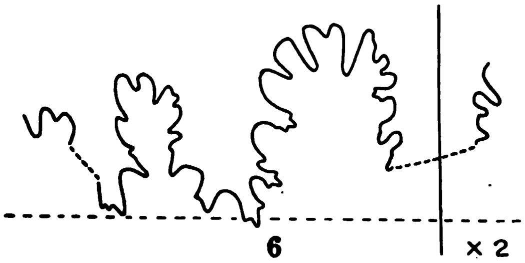

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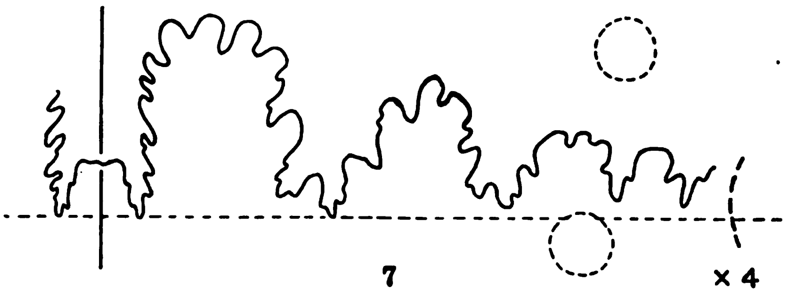

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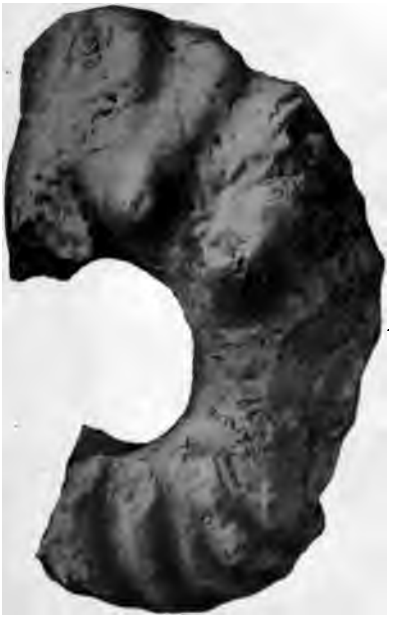

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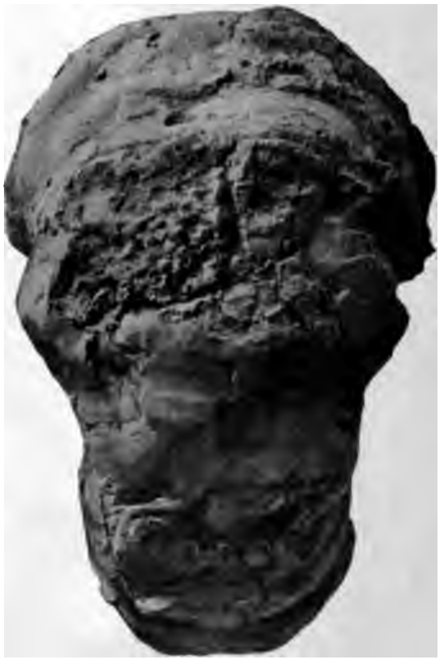

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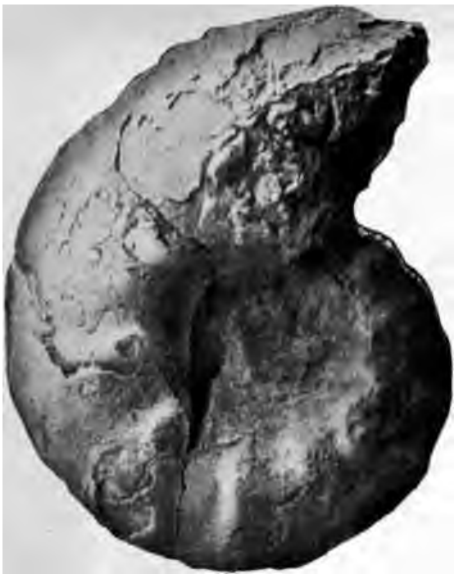
FOSSILS FROM THE COLORADO GROUP OF SOUTHERN MONTANA.

Vascoceras thomi Reeside, n. sp. 1, Side view of outer whorl; 2, rear view of outer whorl; 3, side view of inner whorl; 4, rear view of inner whorl; 5, cross section at diameter of 75 millimeters; 6, suture at diameter of 55 millimeters; 7, suture at diameter of 30 millimeters. (U. S. Nat. Mus. catalog No. 32536.)



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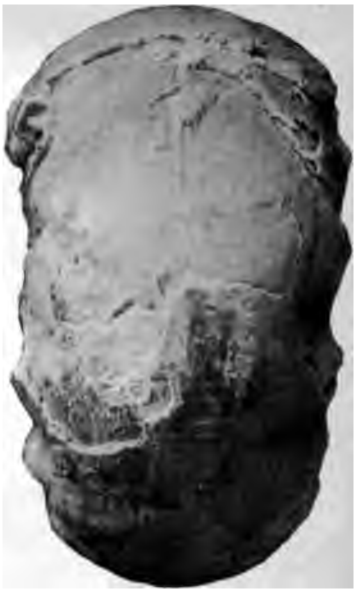

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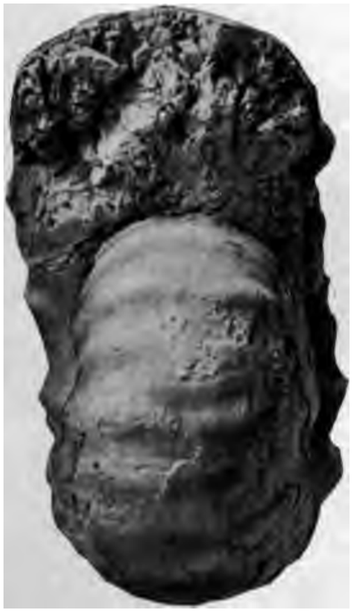

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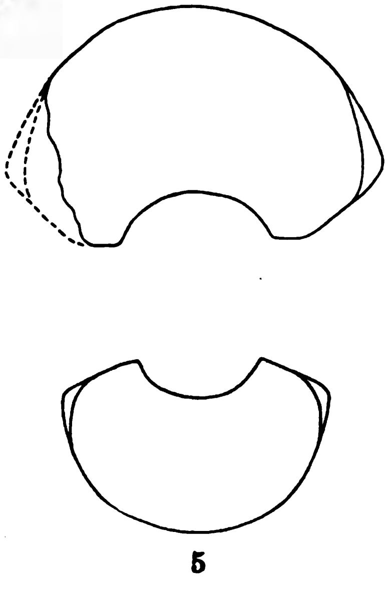

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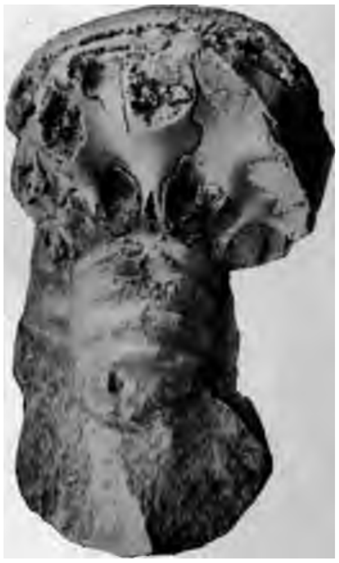

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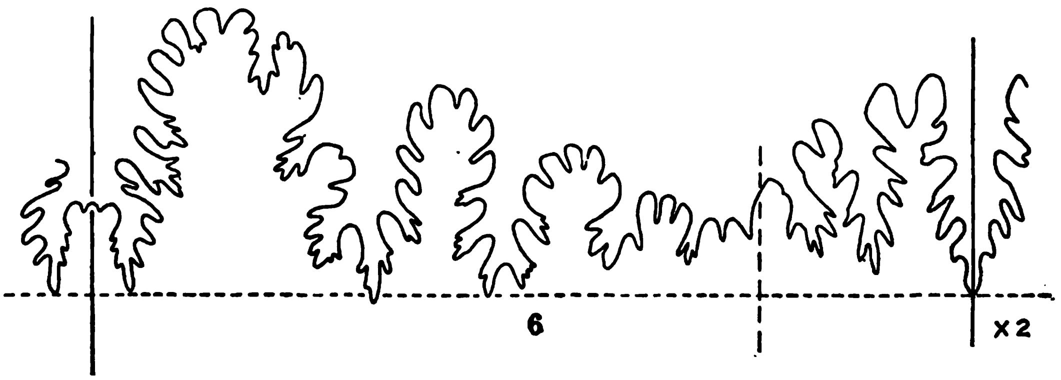

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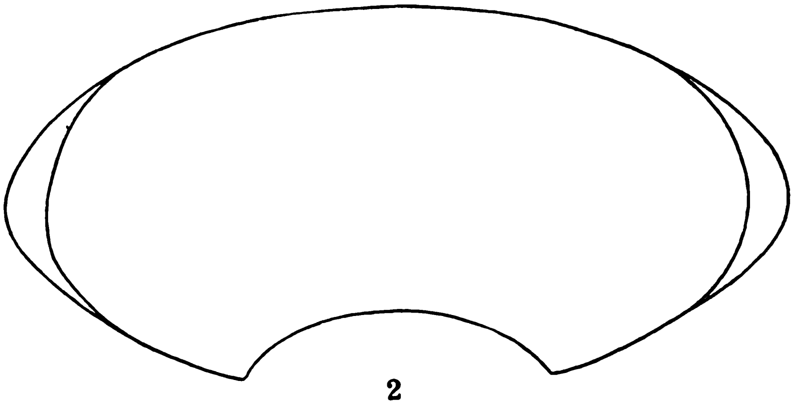
FOSSILS FROM THE COLORADO GROUP OF SOUTHERN MONTANA.

Vascoceras thomi Reeside, n. sp. 1–3, Entire specimen; 1, side view; 2, rear view; 3, front view; 4, rear view with part of outer whorl removed; 5, cross section at diameter of 70 millimeters; 6, suture at diameter of 60 millimeters. (U. S. Nat. Mus. catalog No. 32536.)



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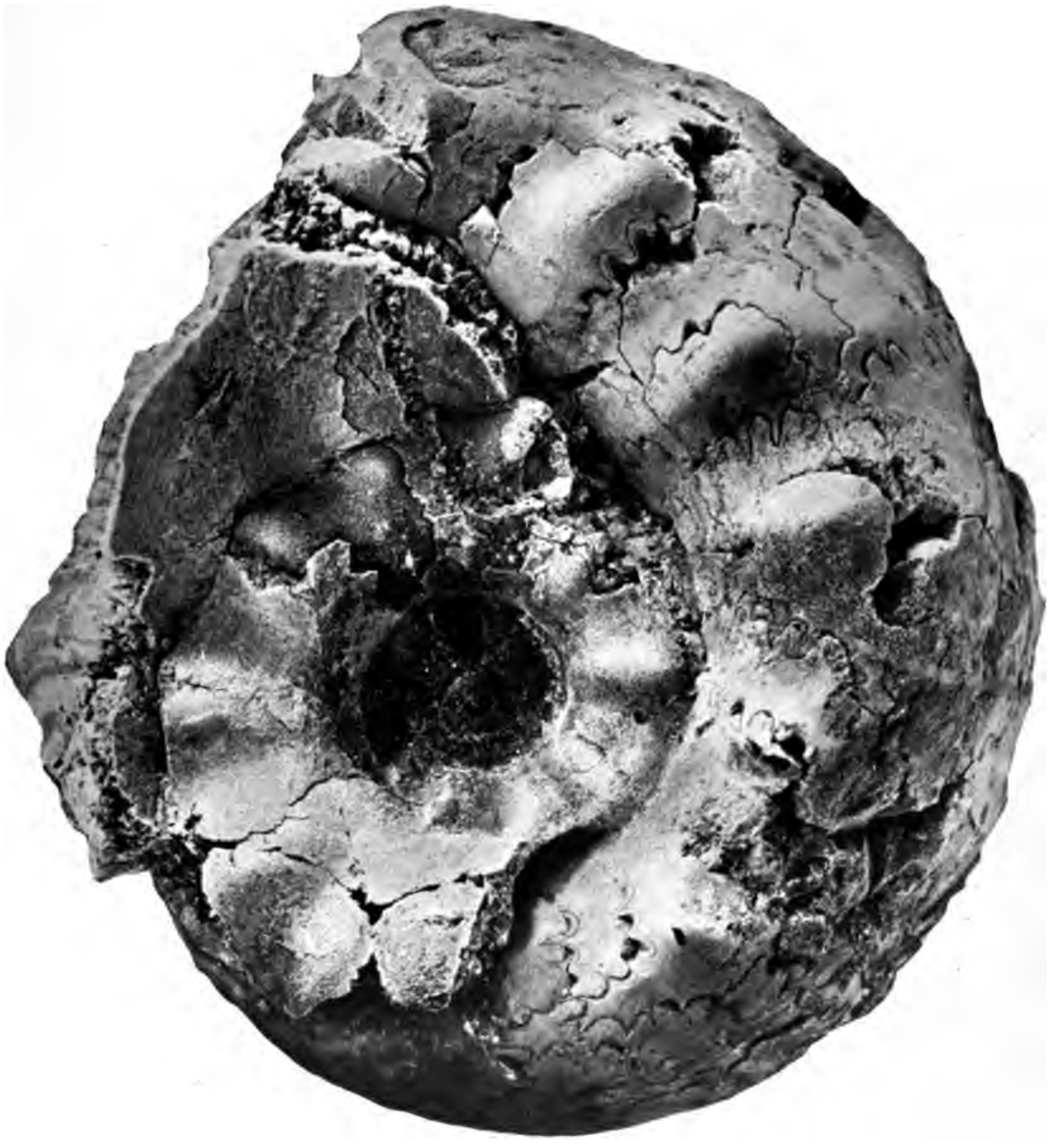
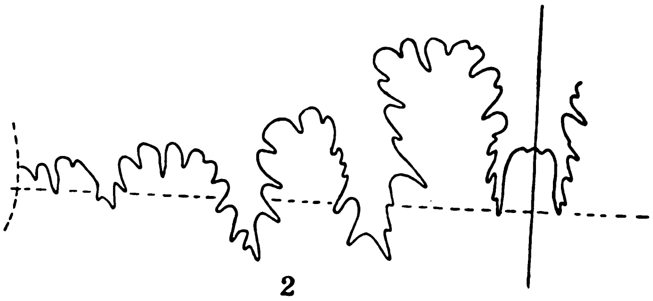


1

FOSSILS FROM THE COLORADO GROUP OF SOUTHERN MONTANA.

Vascoceras moultoni Reeside, n. sp. Type specimen (U. S. Nat. Mus. catalog No. 32537). **1**, Side view; **2**, rear view.



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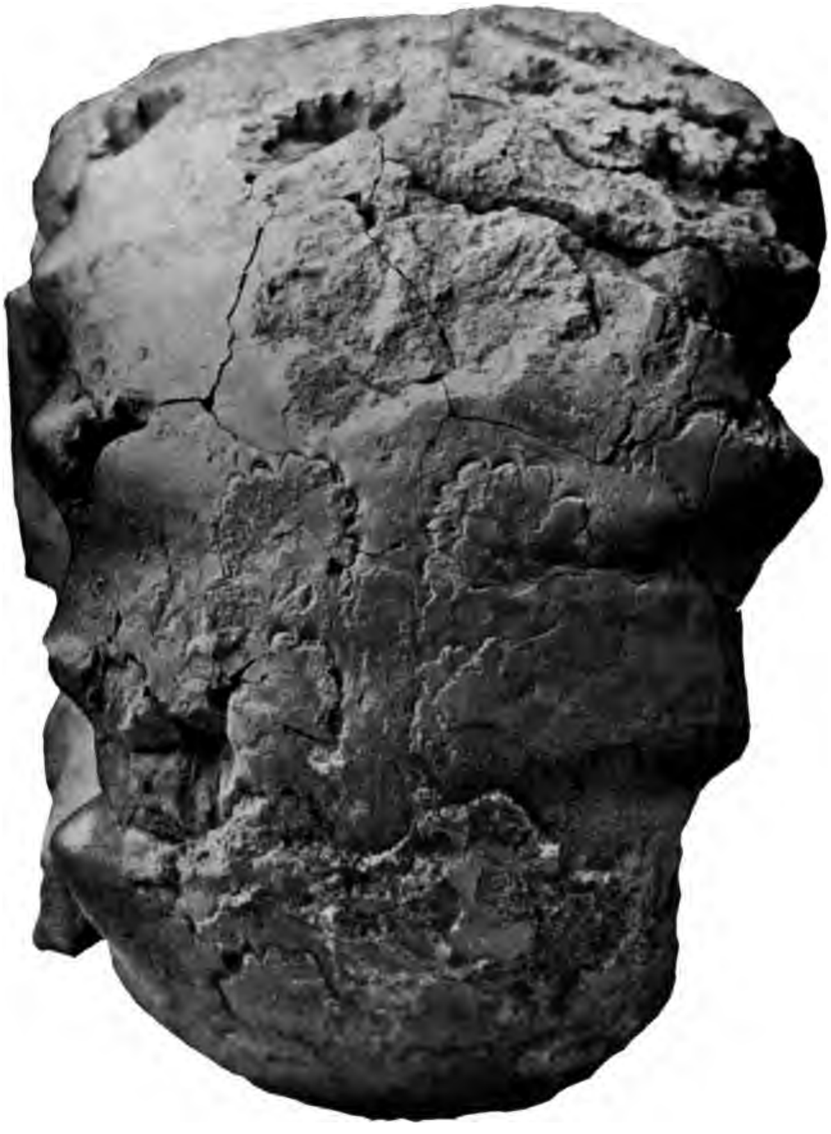

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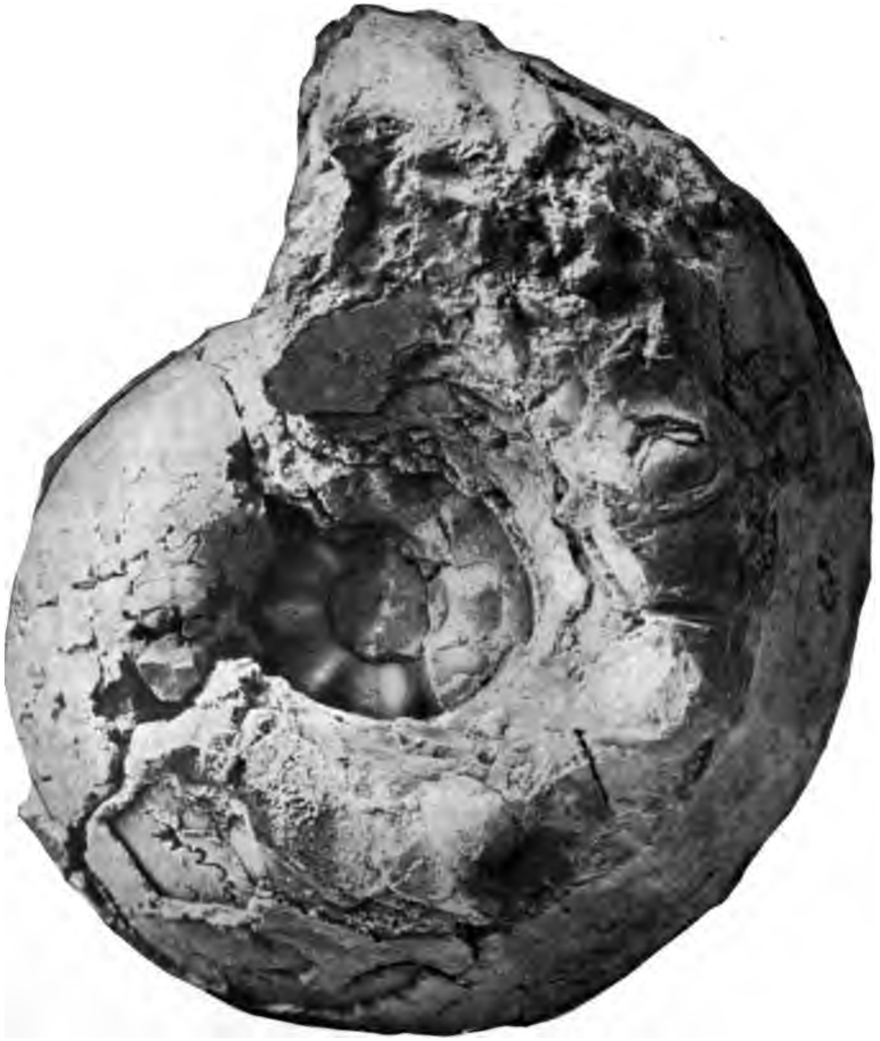
FOSSILS FROM THE COLORADO GROUP OF SOUTHERN MONTANA.

Vascoceras moultoni Reeside, n. sp. Type specimen (U. S. Nat. Mus. catalog No. 32537). **1**, Cross section of whorl at diameter of 150 millimeters; **2**, suture at diameter of 110 millimeters.



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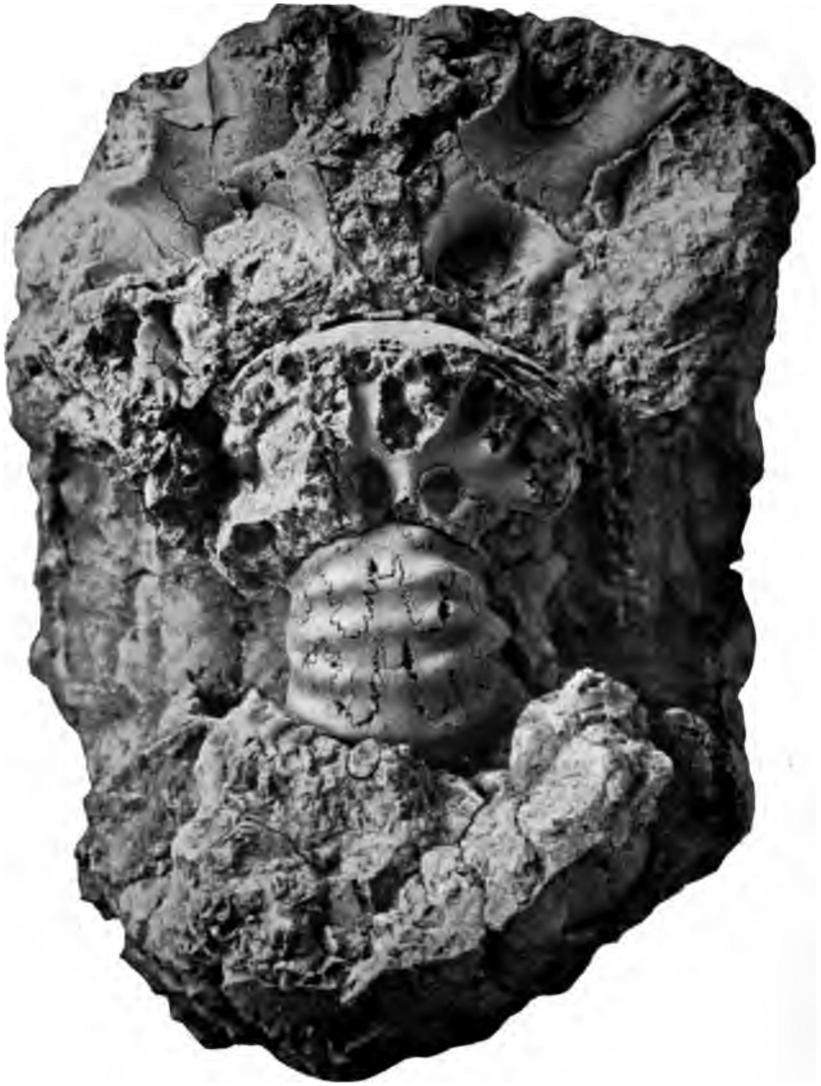

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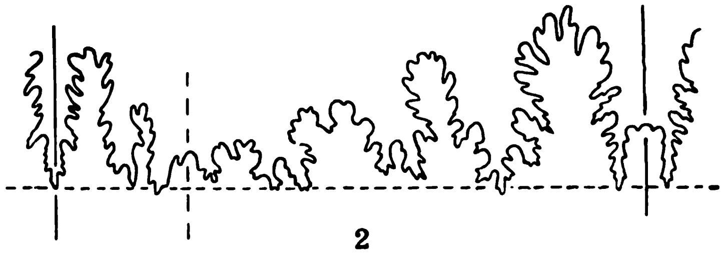
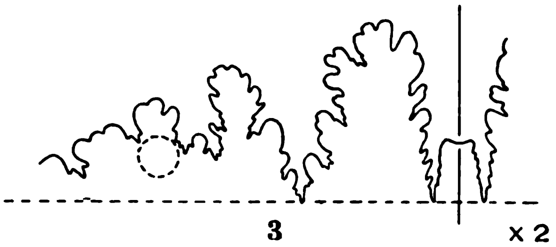
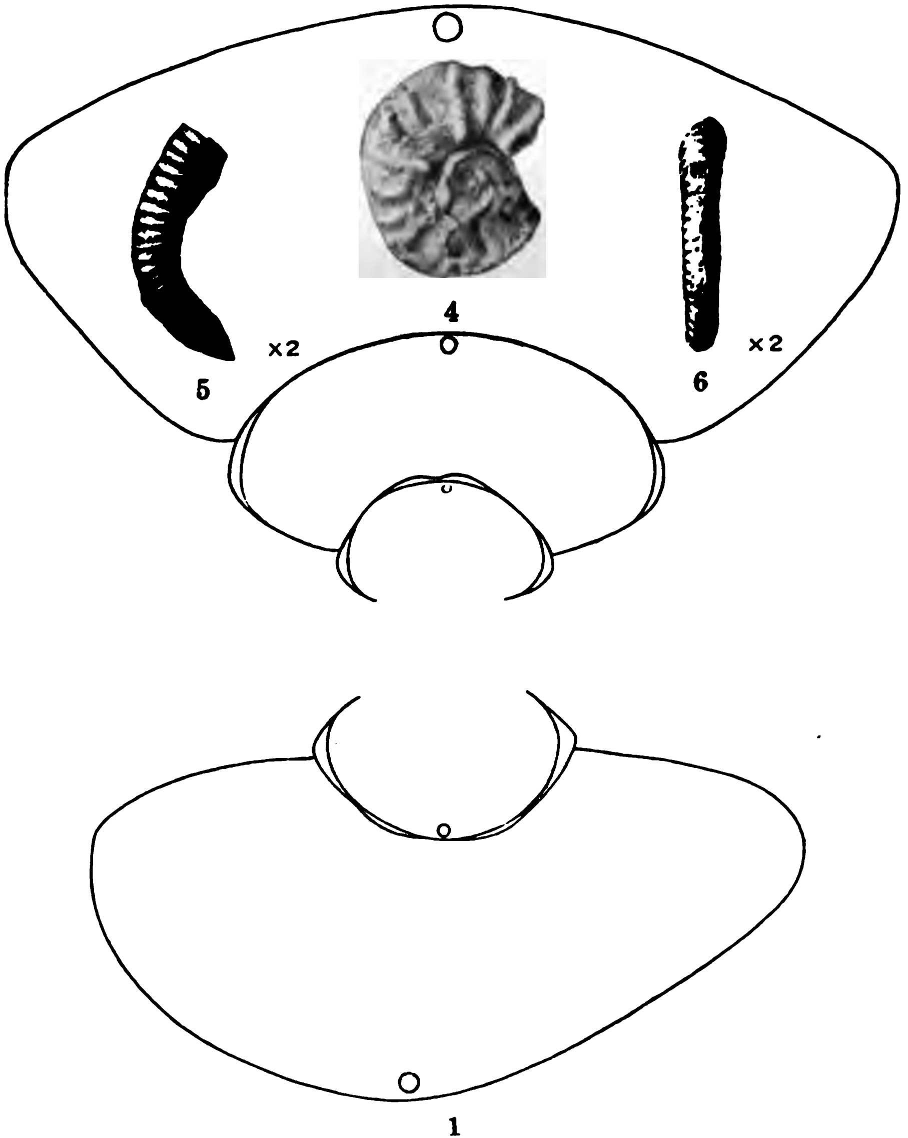
FOSSILS FROM THE COLORADO GROUP OF SOUTHERN MONTANA.

Vascoceras stantoni Reeside, n. sp. Type specimen (U. S. Nat. Mus. catalog No. 32532). **1,** Side view of whole specimen; **2,** front view with part of outer whorl removed.





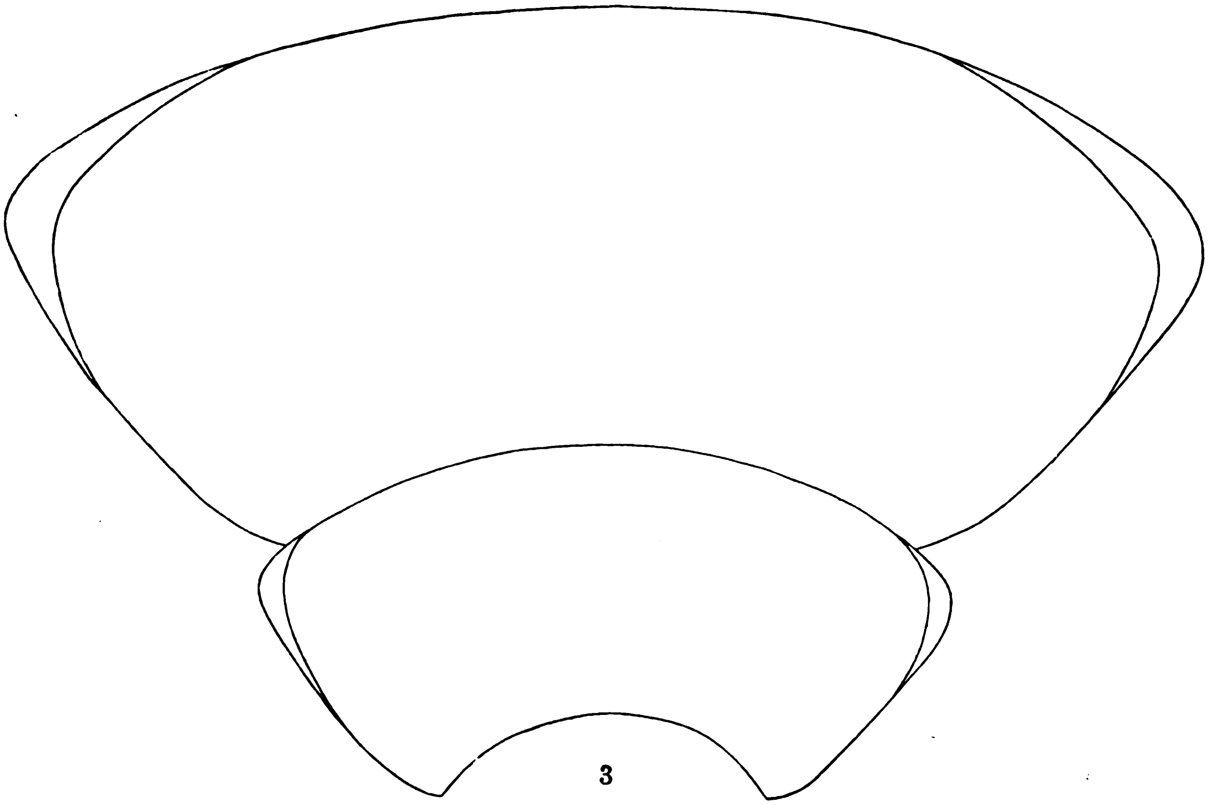


FOSSILS FROM THE COLORADO GROUP OF SOUTHERN MONTANA.

1-3. *Vascoceras stantoni* Reeside, n. sp. Type specimen (U. S. Nat. Mus. catalog No. 32532). 1, Cross section at diameter of 150 millimeters. 2, suture at diameter of 90 millimeters; 3, suture at diameter of 40 millimeters.

4. *Vascoceras* sp. Side view of squeeze showing young whorls. (U. S. Nat. Mus. catalog No. 32538.)

5-6. *Helicoceras pariense* White? 5, Side view; 6, rear view. (U. S. Nat. Mus. catalog No. 32539.)



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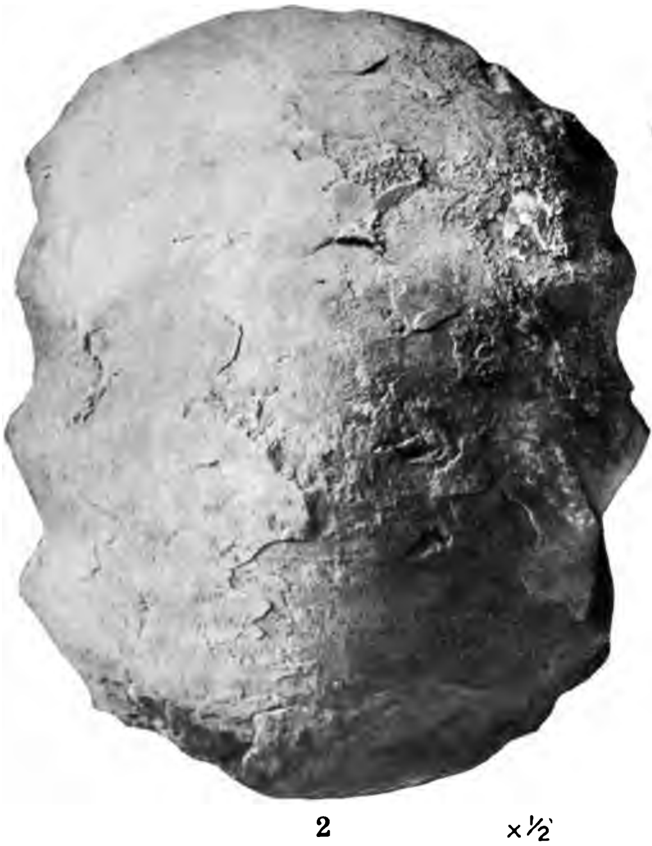

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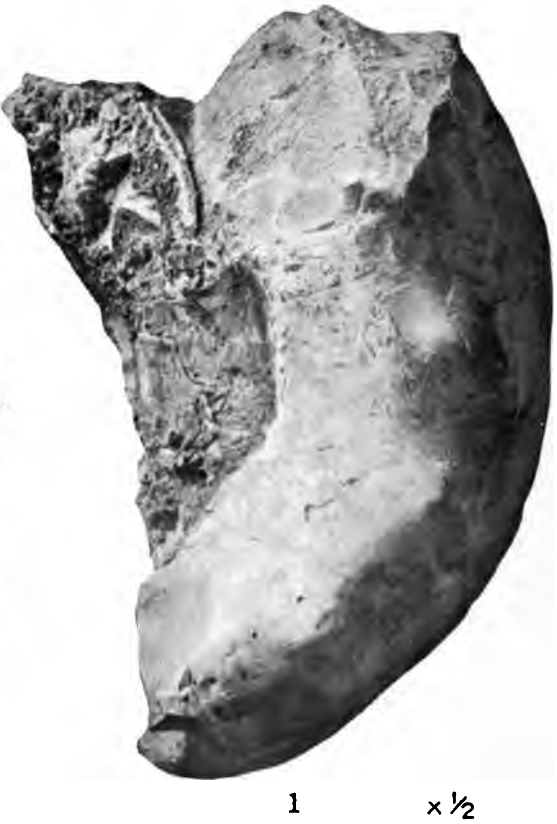

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FOSSILS FROM THE COLORADO GROUP OF SOUTHERN MONTANA.

Vascoceras stantoni Reeside, n. sp. **1**, Side view; **2**, rear view; **3**, cross section, slightly reduced, at diameter of 240 millimeters. (U. S. Nat. Mus. catalog No. 32533.)

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Professional Paper 132—C

NOTES ON THE GEOLOGY OF GREEN RIVER VALLEY BETWEEN GREEN RIVER, WYOMING, AND GREEN RIVER, UTAH

BY

JOHN B. REESIDE, Jr.

Published November 30, 1923

Shorter contributions to general geology, 1923
(Pages 35-50)

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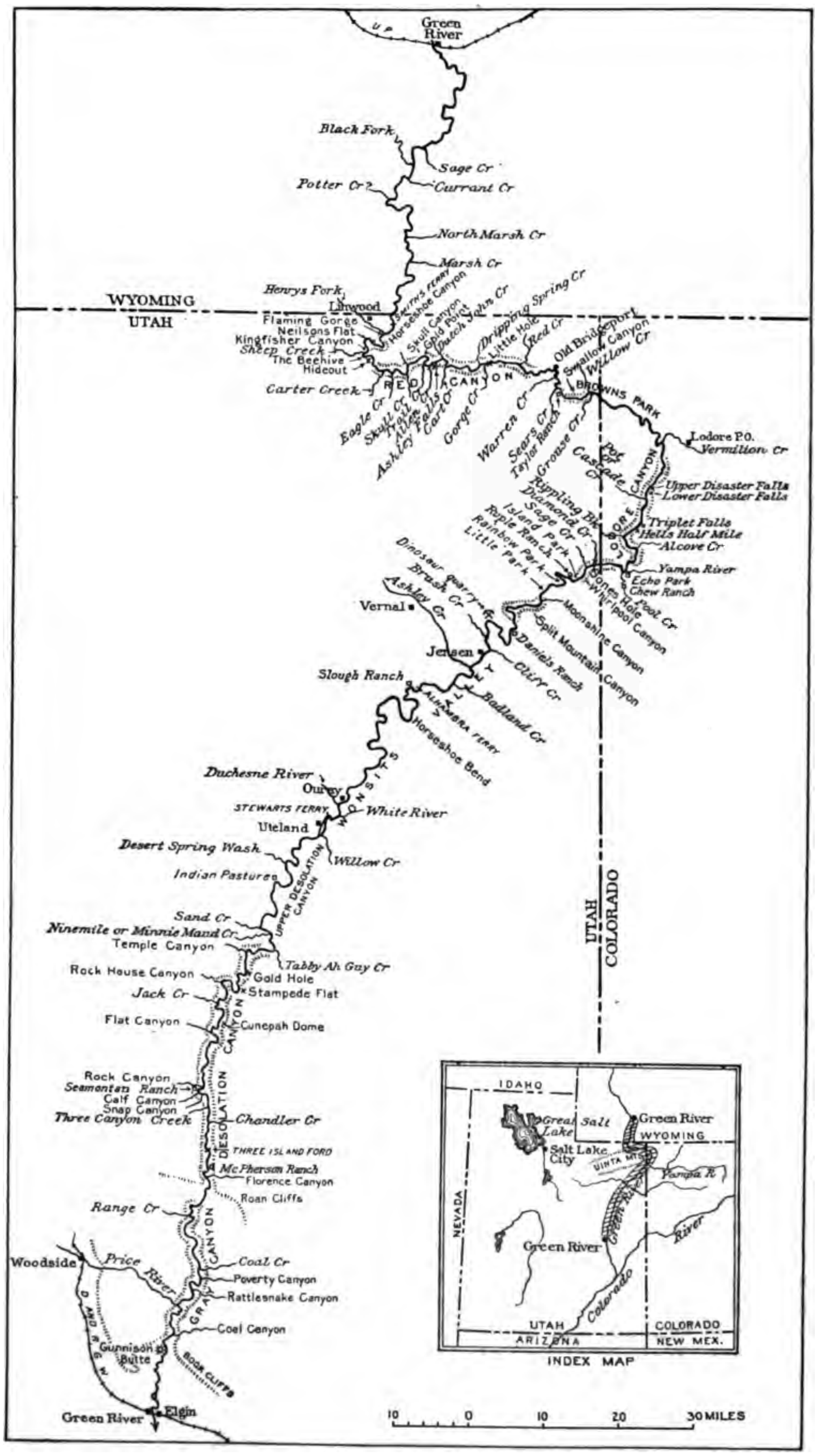

FIGURE 2.—Sketch map of Green River between Green River, Wyo., and Green River, Utah.

NOTES ON THE GEOLOGY OF GREEN RIVER VALLEY BETWEEN GREEN RIVER, WYOMING, AND GREEN RIVER, UTAH.

By John B. Reeside, Jr.

INTRODUCTION.

During July, August, and part of September, 1922, I had the privilege of accompanying a party sent out jointly by the Utah Power & Light Co. and the United States Geological Survey to gather such data as were still needed to complete a study of the power resources of Green River between Green River, Wyo., and Green River, Utah. The chief deficiency to be supplied was a continuous topographic map of the valley in sufficient detail to permit calculation of the storage capacity of any reservoir site that might be used, the stream gradient, and similar features. Maps on a satisfactory scale of a number of isolated stretches of the river had already been made by public or private agencies, and it was necessary to verify them and connect them on a uniform datum. Inasmuch as it was deemed unlikely that a dam higher than 300 feet would be constructed anywhere on the part of the river to be examined, a plane 300 feet above the water surface was made the upper limit of mapping. Over such parts of the valley as had been mapped already the progress of the party was naturally very rapid, and even where no mapping had previously been done, the 300-foot limit set upon the work and the usual narrowness of the valley combined to reduce the extent of the area to be mapped, so that the speed maintained was relatively high. Under this condition of rapid movement it was seldom possible to make more than the most cursory examination of the rocks, though occasionally circumstances permitted more or less detailed observation. The notes here recorded are therefore mostly of a rather generalized character, but as they pertain in part to localities that are difficult of access and not often visited by geologists, and that are at the same time classic in the history of American geology, I venture to to record them for whatever value they may have to other geologists.

GEOLOGIC NOTES.

Green River, Wyo., to the mouth of Henrys Fork.—Most of the part of Green River valley lying between Green River, Wyo., and Henrys Fork is cut in rocks assigned to the Green River formation (lower Eocene). This formation includes a lower division of whitish, gray, and greenish fissile shale, light-colored limestone, and sandstone and an upper division of massive, irregularly bedded brown sandstone with some sandy limestone and shale—the "Tower sandstone" and "plant beds" of Powell.[1] Over much of the way the "Tower sandstone" caps the bluffs along the river, and the gray mass of shaly beds beneath it forms steep slopes. The dips of the beds are low, usually so low that they are not apparent to the eye.

As the mouth of Henrys Fork is approached the influence of the Uinta uplift shows in the appearance of an appreciable northward dip. About 6 miles above the mouth of Henrys Fork this dip increases very much, and the river, running nearly across the strike of the beds, quickly passes out of the Green River formation into the beds mapped by Schultz [2] as Wasatch formation (lower Eocene). These beds consist of white to brown sandstone, gray shale, and red shale and are said to contain some coal.

From the Wasatch exposures the river passes through beds that dip 40°–50° N. and have been assigned by Schultz [2] to the Lewis

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[1] Powell, J. W., Report on the geology of the eastern portion of the Uinta Mountains, pp. 40, 45, U. S. Geol. and Geog. Survey Terr., 1876.

[2] Schultz, A. R., Oil possibilities in and around Baxter Basin, in the Rock Springs uplift, Sweetwater County, Wyo.: U. S. Geol. Survey Bull. 702, pl. 1, fig. 3, 1920.

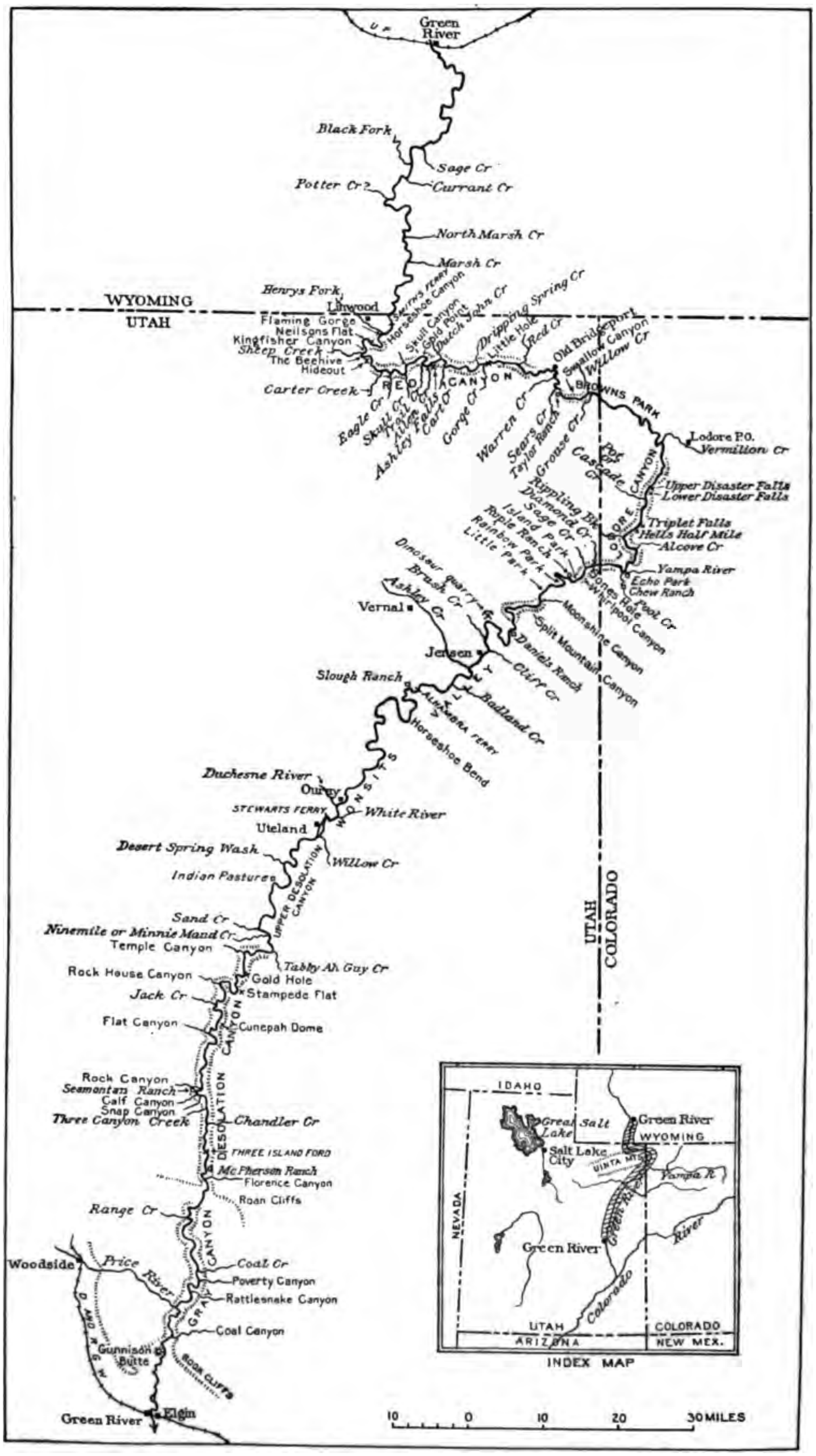

FIGURE 2.—Sketch map of Green River between Green River, Wyo., and Green River, Utah.

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shale, Mesaverde formation, and Hilliard shale (all Upper Cretaceous). These beds are not very well exposed immediately adjacent to the river, and I had no opportunity to study the exposures lying at some distance from the river bank. The Hilliard shale, viewed from a distance of perhaps a mile, appears to be a normal dark-gray marine shale such as one would expect to find in this region. Near the mouth of Henrys Fork the dip is nearly vertical.

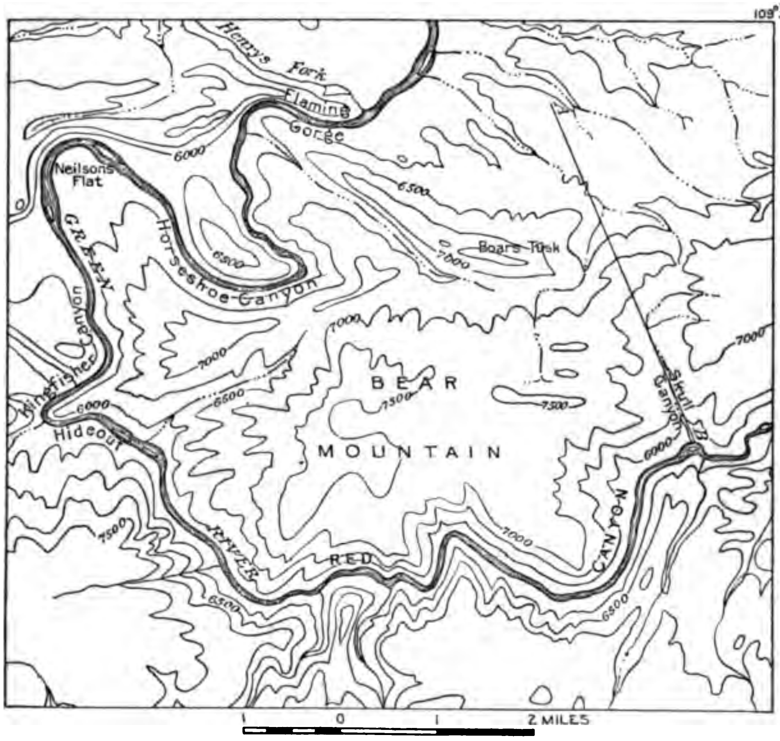

FIGURE 3.—Map showing Green River between the mouth of Henrys Fork and the mouth of Skull Canyon, Daggett County, Utah. Shows also location of section presented in Figure 5 (line *A*-*B*). Adapted in part from Marsh Peak topographic map.

Boars Tusk ridge.—The north flank of the Boars Tusk, a sharp ridge running southeastward from the river just below the mouth of Henrys Fork, shows at the base the sandstone assigned by Schultz[2] to the Frontier formation; above it, topographically, the beds assigned to the Aspen shale (Upper Cretaceous), the Beckwith formation (Jurassic and Cretaceous?), the Twin Creek limestone (Jurassic), and the Nugget sandstone (Jurassic). The south slope shows the red beds assigned by the same author[2] to the Ankareh shale (Triassic?), Thaynes (?) formation (Lower Triassic), and Woodside shale (Lower Triassic). The dip is nearly vertical in the Frontier and Aspen formations, is overturned to the northeast in the lower Beckwith and Twin Creek, and appears to be nearly vertical in the basal sandstone of the Nugget and the underlying red beds. Schultz[3] gives the thickness of the formations here as follows: Frontier formation, 125 feet; Aspen shale, 135 feet; Beckwith formation, 850 feet;[4] Twin Creek limestone, 140 feet; Nugget sandstone, 1,000 feet;[5] Ankareh shale, 300 feet; Thaynes (?) formation, 290 feet; and Woodside shale, 500 feet.

The Frontier formation here, as understood by the writer, consists of a massive brown coarse-grained cross-bedded quartzose sandstone with some thin included lenses of carbonaceous shale and, as nearly as can be determined, is about 100 feet thick. The Aspen shale is a blue-white porcelaneous platy shale containing an abundance of imprints of fish scales. It is the lithologic equivalent of the Mowry shale of the region to the east and north in Colorado and Wyoming. The thickness seemed to be about 225 feet, but the exposures are not entirely satisfactory, and it is possible that part of the interval should go into the Frontier formation. Immediately above the Aspen shale in the slope, but below it, in stratigraphic position, is a coarse brown conglomeratic sandstone. This sandstone is the topmost member of the Beckwith formation of Schultz, but from its lithologic constitution and its position it would be called the Cloverly formation in Wyoming or the Dakota sandstone at many other localities in the Rocky Mountain region. The pebbles in the conglomeratic parts are mostly of white and gray chert and are as much as an inch in diameter. The thickness of the sandstone is 150 feet.

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[2] Schultz, A. R., Oil possibilities in and around Baxter Basin, in the Rock Springs uplift, Sweetwater County, Wyo.: U. S. Geol. Survey Bull. 702, pl. 1, fig. 3, 1920.

[3] Schultz, A. R., op. cit., table opposite p. 36, pp. 73-78, and fig. 3.

[4] In the table opposite p. 36 and in fig. 3 Schultz gives this thickness as 1,500 feet, but on p. 76 it is given as 850 feet, which I believe to be correct.

[5] In the table opposite p. 36 and in fig. 3 Schultz gives this thickness as 1,600 feet, but on p. 78 it is given as 1,000 feet, which I believe to be correct.

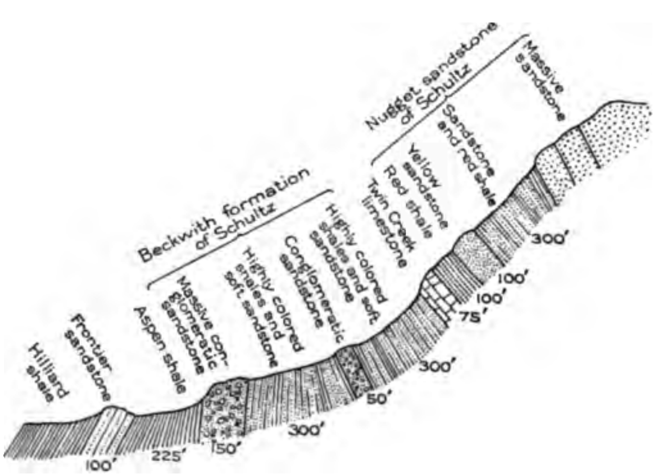

FIGURE 4.—Section of north slope of Boars Tusk ridge, Daggett County, Utah.

Above the sandstone in the slope, but below it stratigraphically, lies a mass of highly colored, variegated shale and soft sandstone about 300 feet thick, which strongly resembles the Morrison formation of eastern Colorado and central Wyoming. These beds form a slope and at most places are not well exposed. The next higher bed in the slope is a second conglomeratic sandstone 50 feet thick, above which more colored shale and soft sandstone, about 300 feet thick and not very well exposed at most places, constitute the basal member of Schultz's Beckwith formation. Above the colored shale last mentioned (below it stratigraphically) lie gray limestone and gray calcareous shale. Some of the limestone layers are fairly massive, but most of them are thin and platy. *Rhynchonella gnathopora* Meek and *Ostrea strigilecula* White were noted, but the beds would undoubtedly yield many more species on careful search. This calcareous unit is the Twin Creek limestone of Schultz and is about 75 feet thick. Above the Twin Creek beds in the slope lie red shale 100 feet thick, then a yellow sandstone about 100 feet thick, then about 300 feet of beds that are not well exposed but seem to consist largely of sandstone interbedded with layers of red shale, all of which together with the overlying sandstone were referred to the Nugget sandstone by Schultz. Above these beds and constituting the comb of the ridge is the massive white, brown, or reddish sandstone forming the base of the Nugget. (See figs. 4 and 7.)

I did not examine the Nugget sandstone and older beds in Boars Tusk ridge with any care and made few notes on them. The basal member of the Nugget sandstone is a thick, massive cross-bedded sandstone that resembles both the sandstone in the lower part of the Sundance formation in Wyoming and the Jurassic sandstone of southern Utah. The red beds were not well exposed in the only place where I crossed them—the gap between Skull Canyon and the drainage north of the ridge. At this locality the red beds are cut off below by the great Uinta fault, which extends for miles along the northern edge of the Uinta Mountain uplift. The beds on the south side of the fault are the much older beds described below as the "Uinta formation," the formations normally occurring between the red beds and the "Uinta formation" having been displaced by the fault. (See fig. 5.)

It seems hardly possible that the Frontier formation, the Aspen shale, and the uppermost part of the Beckwith formation of Schultz are the exact equivalents of the Frontier, Mowry, Thermopolis, and Cloverly formations in Wyoming, but the similarity of lithologic succession is striking. That the beds in the Beckwith formation of Schultz that resemble the Morrison formation are equivalent to that formation is placed beyond doubt by the occurrence of a large fauna of Morrison dinosaurs in beds at the same stratigraphic position near Jensen, Utah. The Twin Creek limestone of Schultz is beyond question equivalent to the upper, calcareous zone of the Sundance formation of central Wyoming. These calcareous beds with the beds below them, down probably to the base of the Nugget sandstone, I consider to represent the interval usually included in the Sundance formation in central Wyoming.

Flaming Gorge, Horseshoe Canyon, Neilsons Flat, and Kingfisher Canyon.—In Flaming Gorge the conspicuous rocks are the rim of Nugget sandstone and the slopes of red beds (Ankareh, Thaynes (?), and Woodside formations of Schultz). At the lower end of the gorge the river passes across the trough marking the outcrop of the rather soft and unresistant upper part of the Park City formation (Permian and Pennsylvanian) into the box canyon cut in the lower part of the Park City formation and the Weber sandstone (Pennsylvanian) and named by Powell Horseshoe Canyon. From Horseshoe Canyon the river passes back into the trough of Park City beds, where a low area near the river is known as Neilsons Flat. From Neilsons Flat the river passes into a second box canyon cut in Weber sandstone and named by Powell Kingfisher Canyon. Kingfisher Canyon is cut off at its lower end by the Uinta fault mentioned above, though here the surface trace of the fault has passed over into older beds and the Weber sandstone lies in contact with the "Uinta formation." (See fig. 3.)

The area including the localities just mentioned is a geologic unit, and the geographic divisions are made by sharp turns in the river. The Nugget sandstone forms a cliff running northeastward and lying to the north and northwest of the area. Beneath it the Ankareh shale of Schultz is composed of dark salmon-red sandstone and shale with a minor proportion of yellowish beds. The upper part of the formation appears to contain softer rock and forms a slope, but the lower part is harder and forms a bench. The formation is bounded at the base by a very irregular, wavy surface of erosion that I take to be the unconformity noted by Schultz.[6] The beds next below the unconformity are darker in color—a brick-red—and weather differently, their surface having a sort of network sculpturing due to small regularly arranged cavities, whereas the surface of the upper beds is fairly smooth. The lower beds are nearly all sandstone and are clearly the Thaynes (?) formation of Schultz. The typical Thaynes formation,[7] near Park City, is essentially a calcareous formation with gray limestone and sandstone, but there is nothing of the sort to be seen here. Beneath the cliff of Thaynes (?) formation lies a long slope underlain by light brick-red sandy shale and soft sandstone and broken near the base by some harder layers that form small benches and by some gray layers interbedded with the red. This unit is evidently the Woodside shale of Schultz and corresponds in a general way to the description of the typical Woodside shale near Park City.[8]

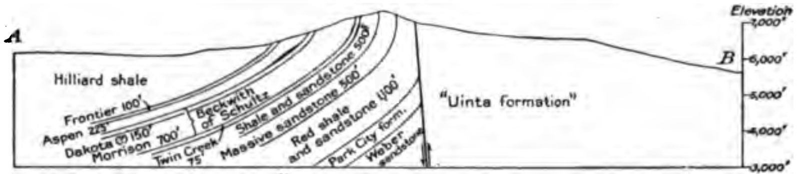

FIGURE 5.—Cross section of ridge east of Boars Tusk ridge, Daggett County, Utah. See Figure 3 for location.

Schultz gives the thickness of the formations as follows: Ankareh, 300 feet; Thaynes, 290 feet; Woodside, 500 feet. I did not make any measurements but believe these figures to be about right. (See fig. 6.)

Boutwell [9] gives the thickness of the Ankareh formation at its typical locality near Park City as over 1,150 feet, the Thaynes formation as 1,290 feet, and the Woodside shale as 1,090 feet. If the beds assigned to these formations near Green River are really equivalent to the typical divisions near Park City, the differences between them and the typical development as described by Boutwell must be ascribed to some such change in passing eastward from Park City as occurs in southern Utah in the Moenkopi formation, also of Triassic age.[10] The Moenkopi formation thins eastward, and the proportion of limestone to noncalcareous beds decreases rapidly in the same direction. The Ankareh formation suggests, in its position beneath the Nugget and its unconformable relation to the underlying beds, the Jelm formation [11] of southern Wyoming, which lies beneath the basal Sundance sandstone and is unconformable on the underlying Chugwater red beds. The Chugwater beds are in turn much like the combined Thaynes (?) and Woodside formations of Green River valley.

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[6] Schultz, A. R. Oil possibilities in and around Baxter Basin, in the Rock Springs uplift, Sweetwater County, Wyo.: U. S. Geol. Survey Bull. 702, tables opposite pp. 24 and 36, 1920.

[7] Boutwell, J. M., Geology and ore deposits of the Park City district, Utah: U. S. Geol. Survey Prof. Paper 77, pp. 55–88, 1912.

[8] Idem, pp. 52–54.

[9] Idem, pp. 52, 56, 58.

The Park City formation lies beneath the Woodside shale and is only indistinctly separated from it. It is described by Schultz [12] as containing near Flaming Gorge in the upper part a gray calcareous shale or shaly limestone 200 feet thick, underlain by a massive cherty limestone 25 feet thick, a phosphate-bearing shale, with chert nodules, 40 to 50 feet thick, and a basal member of massive limestone 100 feet thick resting unconformably on the Weber sandstone. These subdivisions are recognizable without difficulty and maintain very nearly the thicknesses given.

The Weber sandstone is a very massive, resistant brown sandstone, probably in part calcareous. It stands in cliffs along the river at most places where it is exposed. Schultz gives the thickness along Green River as 1,600 feet.

Hideout and Red Canyon.—Hideout is a rather open area between Kingfisher Canyon and Red Canyon. It is perhaps a mile in length measured along the river and affords relatively easy access to the river on either bank. Red Canyon may be considered to extend down the river from Hideout to a point several miles below Red Creek, though it might equally well be considered to end at or above Red Creek. The height and inclination of the canyon walls varies very much—so much, in fact, that perhaps the only uniform character is the constituent rock, the mass of dark-red to red-brown sediments called by Powell [13] the "Uinta group" and by most later geologists the "Uinta quartzite" or "Uinta formation," though by King and Emmons mistakenly identified as Weber sandstone. The name Uinta is more correctly applied to the very much later Tertiary formation that occurs in the Uinta Basin, to the south of the mountains, but as no other acceptable name has been given to the older unit the name "Uinta formation" will be used with quotation marks for it in the present description.

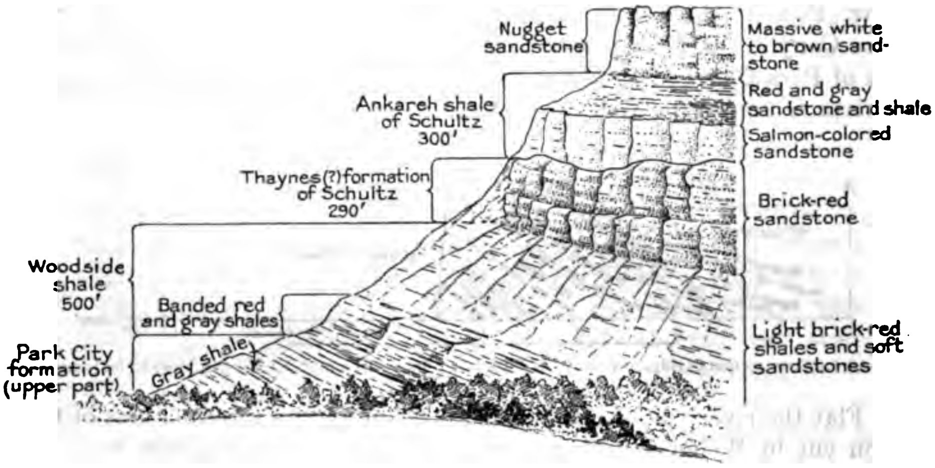
Nugget sandstone
Massive white to brown sandstone
Red and gray sandstone and shale
Ankareh shale of Schultz 300′
Salmon-colored sandstone
Thaynes(?)formation of Schultz 290′
Brick-red sandstone
Woodside shale 500′
Banded red and gray shales
Light brick-red shales and soft sandstones
Park City formation (upper part)
Gray shale

FIGURE 6.—Diagrammatic sketch of bluff northwest of Neilsons Flat, Daggett County, Utah.

The "Uinta formation," the only one exposed in Red Canyon, is a succession of deep-red to maroon resistant sandstone and conglomerate, with lesser amounts of hard red shale. The sandstone is usually dense and is in places changed to a true quartzite in which individual grains are not easily distinguished; locally the color is a deep brown. The shale at some places is greenish. The beds in the upper part of Red Canyon contain more shaly beds proportionately than those in the part farther downstream, though there are some massive beds throughout its length. The canyon walls at many places are débris-covered slopes; at others, cliffs of bare rock. Powell gives the thickness of the "Uinta group" as more than 12,000 feet, and most later writers quote his figures. I had no opportunity to estimate or measure the thickness, but it is certainly very great.

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[10] Reeside, J. B., jr., and Bassler, Harvey, Stratigraphic sections in southwestern Utah and northwestern Arizona: U. S. Geol. Survey Prof. Paper 129, pp. 59-61, 1922.

[11] Knight, C. W., Age and origin of the red beds of southeastern Wyoming (abstract): Geol. Soc. America Bull., vol. 28, p. 168, 1917.

[12] Schultz, A. R., A geologic reconnaissance of the Uinta Mountains, northern Utah: U. S. Geol. Survey Bull. 690, p. 52, 1918; Oil possibilities in and around Baxter Basin, in the Rock Springs uplift, Sweetwater County, Wyo.: U. S. Geol. Survey Bull. 702, tables opposite pp. 24 and 36, 1920.

[13] Powell, J. W., Report on the geology of the eastern portion of the Uinta Mountains, pp. 41, 61, 141, U. S. Geol. and Geog. Survey Terr., 1876.

No fossils have been recorded from the "Uinta formation," and it has been assigned by various writers to the Devonian, Carboniferous, Cambrian, and pre-Cambrian. I can add nothing regarding the age of the formation except that search at many places for features that would aid in fixing the age revealed only obscure trails, mud cracks, and raindrop impressions, of no especial value for this purpose.

Browns Park and Swallow Canyon.—The open valley between Red Canyon and Lodore Canyon, called Browns Park, affords few good exposures near the river, and as it had already been mapped the party's passage through it was too rapid even to see much of those. One exposure of soft dove-gray shale or clay not far below the upper end of the park is probably late river-terrace material, though as far as lithology goes it might equally well be of Tertiary age. Other exposures of brown sandstone are probably part of the late Tertiary Browns Park formation.[14] Swallow Canyon, on the south side of Browns Park, is a relatively shallow canyon cut through the "Uinta formation" by a 4-mile loop of the river which abruptly leaves the soft valley deposits to plunge into the hard sandstone beds and as abruptly returns to the valley.

Lodore Canyon.—From Browns Park the stream passes again into exposures of "Uinta formation" in the deep, narrow course of Lodore Canyon. These exposures differ in no essential respect from those in Red Canyon. The formation has perhaps fewer soft layers, and the walls stand at high angles with but little débris upon them. For the first 12 miles of the canyon, approximately, no rocks except this formation are visible. Then there appears at the top of the canyon walls the first of the post-"Uinta" formations, the Lodore group of Powell.[15] This gradually descends down stream until at a point near the mouth of Alcove Creek it reaches river level. Above the Lodore "group," or Lodore formation, as it would now be called, appear the beds designated by Powell "Redwall group," "Lower Aubrey group," and "Upper Aubrey group."[16] These divisions probably correspond closely to the Mississippian limestone, Pennsylvanian limestone, and combined Weber sandstone and Park City formation of Schultz.[17]

The Lodore formation, as I interpreted it, contains a flaggy basal sandstone of salmon color that is sharply separated from the underlying "Uinta formation" by an unconformity representing an erosion interval.[18] This basal sandstone is overlain by a succession of variegated red, purplish, and green sandy shales and thin sandstones. Possibly there are some thin limestone beds at the top that should also be included in the Lodore formation, though I tentatively put all the limestones into the next higher unit. The shale unit is softer than the underlying beds and the succeeding Carboniferous limestone and makes a marked slope. The basal sandstone is about 150 feet thick and the shale unit about 300 feet thick. Powell gives 460 feet as the thickness of his Lodore "group," and the round figure of 500 feet is cited by most later writers. No fossils have been recorded from the Lodore formation but it is supposed by recent writers to be Cambrian, both from its position in the section and its resemblance to beds in the Tonto group of the Grand Canyon. The Carboniferous fossils noted by Powell on page 56 of the report cited were very probably out of place.

The beds designated by Powell "Redwall group" and "Lower Aubrey group" include in the lower part much massive cream-colored to brown cherty limestone very similar to the Madison limestone (lower Mississippian) of central Wyoming; and in the upper part a succession of red, pink, and purplish shale and sandstone and gray and pinkish limestone, all in relatively thin layers and as a mass much like the beds commonly assigned to the Amsden formation (Pennsylvanian and upper Mississippian) in central Wyoming. I estimate the thickness of the upper and lower divisions as 1,000 to 1,200 feet each.

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[14] Powell, J. W., op. cit., pp. 40, 44, 168.

[15] Powell, J. W., op. cit., pp. 41, 56, 147.

[16] Idem., pp. 41, 54-55, 147-149.

[17] Schultz, A. R., Oil possibilities in and around Baxter Basin, in the Rock Springs uplift, Sweetwater County, Wyo.: U. S. Geol. Survey Bull. 702, table opposite p. 36, 1920.

[18] Powell, J. W., op. cit., pp. 144-145.

Above the beds of Powell's "Lower Aubrey group" comes the Weber sandstone, here as in Horseshoe and Kingfisher canyons a very massive, much cross - bedded yellow - brown quartzose sandstone that rises in sheer unbroken walls for hundreds of feet.

At the extreme lower end of Lodore Canyon, just at the edge of Echo Park, a fault, visible on the right bank of the river and striking in a direction somewhat east of north, brings the lower part of Powell's "Redwall group" into contact with the extreme top of his "Lower Aubrey group." The extension of this same fault southward is clear in Mitten Park and the basin of Pool Creek. (See below.)

Echo Park, Pool Creek, and Mitten Park.—Green River, on leaving Lodore Canyon, follows for some miles a course shaped like a narrow U with the open end to the north. The east limb of this U receives Yampa River from the east, and the bend receives Pool Creek from the south. The narrow open bottom adjacent to the mouths of these streams is Echo Park or Pat's Hole. Farther downstream, at the top of the west limb of the U, another small open bottom is known as Mitten Park. From Mitten Park the river passes abruptly into Whirlpool Canyon.

Echo Park is walled in by sheer cliffs of Weber sandstone, which likewise forms Steamboat Rock, the great mass that fills the area in the center of the U. The lower course of Pool Creek is a narrow box canyon, likewise in the Weber sandstone, though in about 2 miles the creek bed rises above it, through the Park City beds, and runs upon red beds. These red beds lie in a small basin bordered on the west by the fault mentioned above and possibly by another on the south. The Woodside shale appears to be much as on the north side of the mountains, and the Thaynes (?) about the same except for the occurrence of some heavy beds of brown sandstone. I believe that the supposed Ankareh and later beds have been removed here by erosion.

In Mitten Park the rocks are tilted to a high angle in proximity to the fault and are even overturned. The downthrow is on the east and the upthrow on the west, bringing above the river level several hundred feet of the upper part of the "Uinta formation."

I made no estimate of thicknesses in this region, though the Weber sandstone is certainly in excess of 1,000 feet.

Whirlpool Canyon.—At the upper end of Whirlpool Canyon the uppermost several hundred feet of the "Uinta formation" appears west of the fault described above. The normal succession of formations appears above it—Lodore formation, "Redwall group," and "Lower Aubrey group." The Lodore formation has about the same constitution and thickness as in Lodore Canyon; likewise the lower Madison-like part of Powell's divisions and the upper Amsden-like part. The irregular contact of the Lodore formation on the "Uinta formation" is especially well shown. The formations dip downstream, and at the lower end of the canyon the Weber sandstone appears. It is bent sharply downward and cut off by a fault, which runs about parallel to that of the upper end, with the downthrow on the west and the upthrow on the east.[19] Whirlpool Canyon therefore seems to cross an uplifted fault block, with the Mitten Park fault on the east and the Island Park fault on the west.

Island Park.—The area along the river between Whirlpool Canyon and Split Mountain Canyon is divided by the local residents and on some maps into three small parks. These are merely large bottoms separated by low ridges and are called, in order downstream, Island Park, Rainbow Park, and Little Park. The rocks of this area, often called as a whole Island Park, lie in an unsymmetrical syncline with axis plunging a little south of east and with the eastern tip truncated by the fault at the eastern edge of Island Park. The formations present extend from the Weber sandstone to the Hilliard shale, inclusive. The character of the rocks is best shown in the following section:

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[19] See Schultz, A. R., A geologic reconnaissance of the Uinta Mountains, northern Utah: U. S. Geol. Survey Bull. 690, pl. 5, 1918.

Section measured in Island Park.

[See also fig. 7.]

	Feet.
Measured northwest of Rainbow Park.	
Hilliard shale.	
Frontier formation of Schultz:	
Sandstone, massive, gray to yellow	35
Shale, yellow, sandy	33
Sandstone, massive, gray to yellow	40
Shale, yellow to gray, in part sandy	130
Aspen shale of Schultz: Shale, hard, platy, bluish-white, with abundant fish scales. Exactly like Mowry shale in Wyoming	80
Beckwith formation of Schultz:	
Sandstone, massive, brown to gray, coarse, containing few lenses of pebbles the size of wheat. (Where measured the upper part of this unit is in almost direct contact with Aspen shale, but along the strike the upper 50 feet changes to very dark shale)	75
Shale, brown to dark gray, with some thin beds of brown sandstone. Not as dark as might be expected at this horizon	38
Sandstone, coarse, brown to gray. No pebbles seen	8
Shale, variegated purple, green, gray; sandstone, soft, whitish; and sandstone, brown, hard. Contain bone fragments and gastroliths at a number of horizons. Beds change rapidly both vertically and horizontally. Possibly some of the basal beds may belong to the underlying marine Jurassic, but they did not furnish clear evidence of marine origin. Thickness calculated from topographic data	700
Measured 1 mile west of Ruple ranch.	
Twin Creek formation of Schultz:	
Shale, greenish gray, with layers of platy argillaceous sandstone and some lenses of soft yellow sandstone. Not sharply separated from overlying unit. Sandstone layer 10 feet above base contains *Rhynchonella gnathophora* Meek, *Ostrea* sp. undetermined, *Tancredia warrenana* Meek and Hayden, *Trapezium?* sp	40
Sandstone, blocky, light brown, fine-grained; contains *Rhynchonella*, *Ostrea*, and other fossils very poorly preserved	3
Sandstone, soft, gray-white, cream-colored to yellow, argillaceous; at most places weathers back like shale, at others stands out as ledges; contains lenses of greenish shale. No fossils seen	85
Shale, greenish gray, with thin layers of sandy brownish limestone and nodules of dense blue limestone. Contains *Cidaris?* sp., bryozoan, *Parallelodon?* n. sp., *Pinna* sp., *Eumicrotis curta* (Hall), *Ostrea strigilecula* White, *Cardinia?* n. sp., *Trigonia quadrangularis* Hall and Whitfield, *Camptonectes platessiformis* White, *Modiola pertenuis* Meek and Hayden, *Pleuromya newtoni* Whitfield, *Astarte packardi* White, *Tancredia? inornata* Meek and Hayden, *Dosinia jurassica* Whitfield, *Quenstedticeras? hoveyi* Reeside, *Cardioceras* cf. *C. cordiforme* (Meek and Hayden), *Cardioceras* sp., *Belemnites densus* Meek and Hayden	50
Nugget sandstone of Schultz:	
Sandstone, platy, gray to cream-colored, with thin shale layers. Grades into overlying beds	15
Sandstone, massive, cream-colored, cross-bedded	20
Sandstone, platy, gray, interleaved with thin layers of green, gray, and purple shale. The lower part contains clay-pellet conglomerates, and the base is a sinuous line. Probably no unconformity of much magnitude, as both these beds and the underlying beds are shallow-water deposits.	
Sandstone, massive, cream-colored to brown, cross-bedded, in a single bed. Cross-bedding seems to be of the current type	75
Measured in Little Park.	
Shale, brick-red with some gray streaks	200
Sandstone, gray to yellow, locally salmon-colored, cross-bedded, very massive	560
Sandstone and shale, alternating in thin beds, red and white	14
Ankareh shale of Schultz:	
Shale, sandy, red with some white streaks and gray layers	50
Sandstone, salmon-colored, massive, medium grained	15
Shale and soft sandstone, mostly brick-red	160
Grit, coarse, white, yellow, and pink, with lenses of pebbles of quartz and chert 1 inch or less in diameter; basal part has pebbles as much as 2 inches in diameter	30
Unconformity.	
Thaynes (?) and Woodside formations of Schultz:	
Shale and sandstone, brick-red, without any prominent subdivisions; estimated at	1,000
Park City formation.	

Split Mountain Canyon.—The rocks exposed in Split Mountain Canyon (sometimes locally called Black Mountain Canyon) form a sharp unsymmetrical anticline whose axis runs about due west. The river enters the canyon at right angles to the strike of the rocks on the north limb but on reaching the axis of the fold runs parallel to it for about 5 miles, then at right angles to the strike across the south limb. The upper end of the canyon is in Weber sandstone, but the dip is steep and soon brings up the upper part of the "Lower Aubrey group" of Powell (Amsden-like beds) and in places along the axis Powell's "Redwall group" (Madison-like beds). On the south limb the reverse succession is present, and the canyon ends at the top of the Weber sandstone.

Wonsits Valley.—The name Wonsits Valley was applied by Powell[20] to the region extending from the lower end of Split Mountain Canyon to the mouth of Duchesne River. It is here extended arbitrarily southwestward to include the valley as far as the mouth of Willow Creek.

Immediately following the Weber sandstone at the lower end of Split Mountain Canyon comes a succession of red beds, Nugget sandstone, etc., nearly identical with that in Island Park. These beds dip very steeply but are not as well exposed near the river as in Island Park. Owing to the steep dip the river passes through the older beds in a short distance and then runs upon the Cretaceous a considerable distance, but the exposures are rather poor because of the abundance of river-terrace material. Along this part of the river a number of attempts have been made to exploit the river terraces for placer gold, but they have not yet been wholly successful.

At a point about 6 miles above Jensen the river approaches closely the outcrops of the pre-Cretaceous rocks. Near this point the Carnegie Museum of Pittsburgh, Pa., has for years been taking dinosaur remains from a quarry in beds of Morrison age. A stratigraphic section in the neighborhood of the quarry is as follows:

Section measured at Carnegie Museum dinosaur quarry, above Jensen.

[See also fig. 7.]

	Feet.
River-terrace materials, underlain by Hilliard shale.	
Frontier formation of Schultz:	
Sandstone, fairly coarse, gray to brown, cross-bedded	22
Shale, yellow, sandy, with thin layers of gray sandstone	158
Aspen shale of Schultz:	
Shale, bluish gray, hard, platy; contains many fish scales	50
Shale, yellowish, sandy	37
Beckwith formation of Schultz:	
Sandstone, gray to brown, locally weathering pink, coarse, conglomeratic, cross-bedded	35
Shale, rusty brown and drab	27
Sandstone, gray to brown, in thin beds	10
Shale, rusty brown and drab	37
Sandstone, ripple-marked, coarse, cross-bedded, brown to gray; rusty in places. This bed seems to be variable in thickness and may even be absent a short distance to the west	37
Shale, gray, violet, and greenish, with lenses of greenish argillaceous sandstone, grit, and conglomerate that weather to a chocolate-brown; highly variable unit	279
Sandstone, greenish, conglomeratic; weathers brown. Horizon of dinosaur quarry	10
Shales and sandstone, variegated; like second unit above	506
Twin Creek formation of Schultz:	
Sandstone, fine grained, fissile, beautifully ripple marked and rain pitted, greenish gray, with considerable interbedded shale. Some layers contain *Ostrea* sp	40
Sandstone, platy, ripple marked, gray, fine grained; contains *Rhynchonella gnathophora* Meek and *Tancredia warrenana* Meek and Hayden	2
Shale, greenish gray, with some platy sandstone of same color	65
Sandstone, brown, limy; contains *Ostrea strigilecula*	1
Shale, dark gray, almost black, containing dense blue limestone in concretions	42
Limestone, gray, coarse, sandy; contains *Eumicrotis curta* (Hall), *Ostrea strigilecula* White, *Camptonectes platessiformis* White, *Astarte packardi* White, *Tancredia? inornata* Meek and Hayden, *Tancredia* sp., *Dosinia jurassica* Whitfield?, *Cardioceras russelli* Reeside, *Cardioceras hyatti* Reeside, *Cardioceras cordiforme* Meek and Hayden, *Cardioceras* aff. *C. wyomingense* Reeside, *Cardioceras* sp	1
Shale, greenish gray, with limestone in nodules and containing *Ostrea strigilecula* White and *Eumicrotis curta* (Hall)	27
Nugget sandstone of Schultz:	
Sandstone, very massive, cross-bedded, medium grained, yellow to gray	91
Shale and platy sandstone, yellow to gray	12
Sandstone, massive, gray to yellow, cross-bedded, medium grained	120
Shale, variegated, gray and brick-red	107
Sandstone, very massive, yellow to gray; forms here an impassable ridge; must be some hundreds of feet thick.	

For a short distance below the dinosaur quarry there are very good exposures of Hilliard shale close to the river, but over much of the way to Jensen the exposures are poor. The rocks lie in a syncline plunging to the west, as shown by Gale[21] and Schultz.[22] An anticline, also plunging westward and with its axis passing close to Jensen, brings up Frontier sandstone just east of the town. Downstream from Jensen the river passes through higher and higher beds. About 6 miles southwest of Jensen sandstone and shale containing

---

[20] Powell, J. W., Map of Green River from the Union Pacific Railroad to the mouth of White River, 1873; Exploration of the Colorado River of the West and its tributaries, explored in 1869 ,1870 ,1871 and 1872, p. 44, 1875.

[21] Gale, H. S., Coal fields of northwestern Colorado and northeastern Utah: U. S. Geol. Survey Bull. 415, pl. 21, 1910.

[22] Schultz, A. R., A geologic reconnaissance of the Uinta Mountains, northern Utah: U. S. Geol. Survey Bull. 690, pl. 5, 1916.

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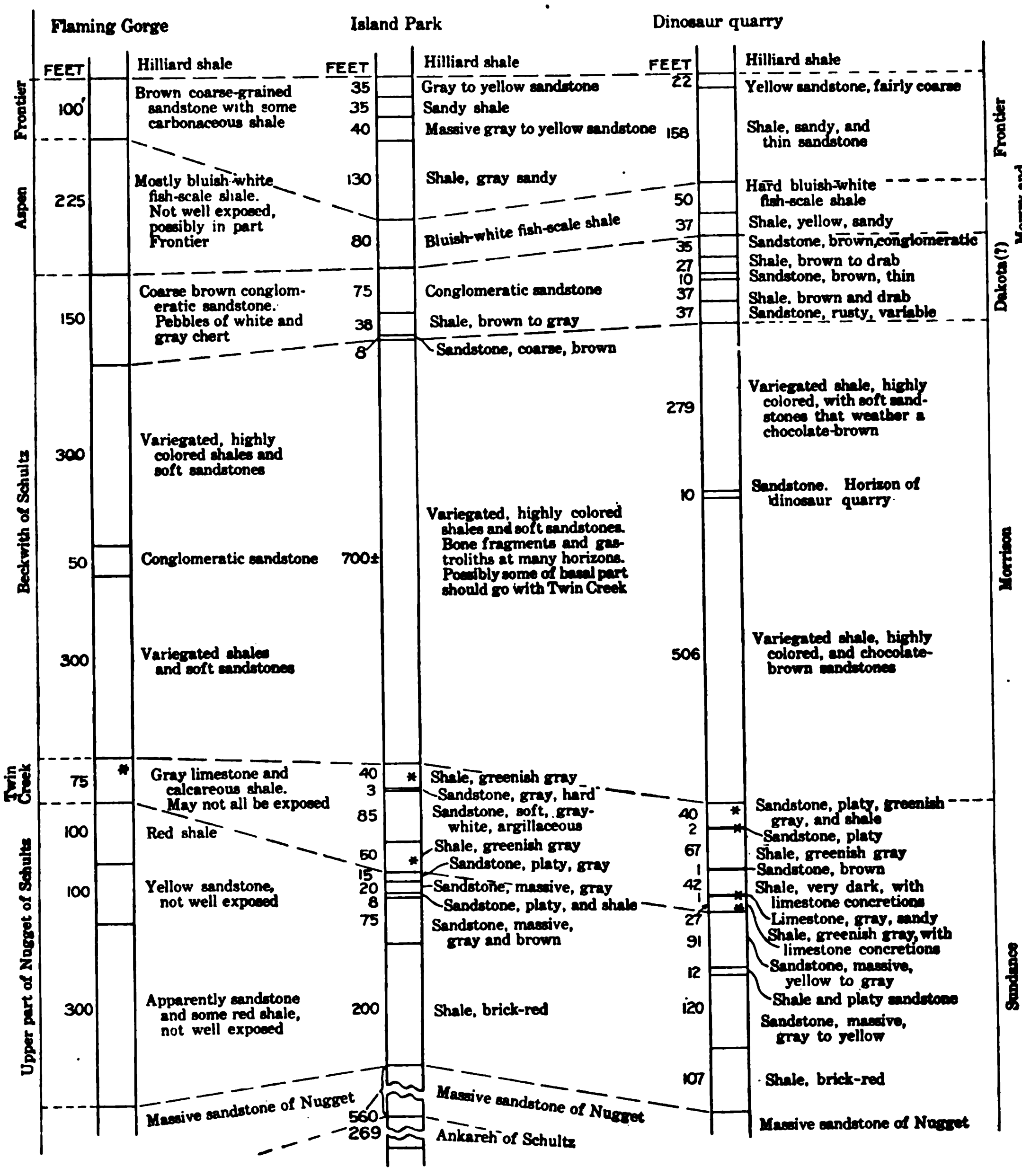
many red beds appear. These beds are relatively soft and lack the hard sandstones present in the Wasatch. I take them to be the Tertiary beds assigned to the Bridger formation (middle and upper Eocene) and Uinta formation (upper Eocene). This is the real Uinta formation. These beds have a south dip at their northern edge. Farther downstream they lie practically flat, but about at the neck of Horseshoe Bend they begin to dip northward. From that point on to a locality some distance above Ouray only these red beds are visible, but at this locality gray beds appear at river level and the red element is less striking.


Flaming Gorge
Island Park
Dinosaur quarry
FEET
Frontier
100
Aspen
225
150
Beckwith of Schultz
300
50
300
Twin Creek
75
Upper part of Nugget of Schultz
100
100
300
Hilliard shale
Brown coarse-grained sandstone with some carbonaceous shale
Mostly bluish-white fish-scale shale. Not well exposed, possibly in part Frontier
Coarse brown conglomeratic sandstone. Pebbles of white and gray chert
Variegated, highly colored shales and soft sandstones
Conglomeratic sandstone
Variegated shales and soft sandstones
*
Gray limestone and calcareous shale. May not all be exposed
Red shale
Yellow sandstone, not well exposed
Apparently sandstone and some red shale, not well exposed
Massive sandstone of Nugget
FEET
35
35
40
130
80
75
38
8
700±
40
3
85
60
15
20
8
75
200
560
269
Hilliard shale
Gray to yellow sandstone
Sandy shale
Massive gray to yellow sandstone
Shale, gray sandy
Bluish-white fish-scale shale
Conglomeratic sandstone
Shale, brown to gray
Sandstone, coarse, brown
Variegated, highly colored shales and soft sandstones. Bone fragments and gastroliths at many horizons. Possibly some of basal part should go with Twin Creek
*
Shale, greenish gray
Sandstone, gray, hard
Sandstone, soft, gray-white, argillaceous
Shale, greenish gray
*
Sandstone, platy, gray
Sandstone, massive, gray
Sandstone, platy, and shale
Sandstone, massive, gray and brown
Shale, brick-red
Massive sandstone of Nugget
Ankareh of Schultz
FEET
22
158
50
37
35
27
10
37
37
279
10
506
40
2
67
1
42
1
27
91
12
120
107
Hilliard shale
Yellow sandstone, fairly coarse
Shale, sandy, and thin sandstone
Hard bluish-white fish-scale shale
Shale, yellow, sandy
Sandstone, brown, conglomeratic
Shale, brown to drab
Sandstone, brown, thin
Shale, brown and drab
Sandstone, rusty, variable
Variegated shale, highly colored, with soft sandstones that weather a chocolate-brown
Sandstone. Horizon of dinosaur quarry
Variegated shale, highly colored, and chocolate-brown sandstones
*
Sandstone, platy, greenish gray, and shale
*
Sandstone, platy
Shale, greenish gray
Sandstone, brown
Shale, very dark, with limestone concretions
*
Limestone, gray, sandy
*
Shale, greenish gray, with limestone concretions
Sandstone, massive, yellow to gray
Shale and platy sandstone
Sandstone, massive, gray to yellow
Shale, brick-red
Massive sandstone of Nugget
Frontier
Mowry and Thermopolis
Dakota(?)
Morrison
Sundance

* Marine Jurassic fossils

FIGURE 7.—Diagram showing correlation of sections near Flaming Gorge, Daggett County, and in Island Park and near the Carnegie Museum dinosaur quarry, Uinta County, Utah.

Upper Desolation Canyon.—The name Desolation Canyon was applied by Powell[23] to the stretch of valley from a point somewhere in the neighborhood of Indian Pasture downstream to the Roan Cliffs. For the present description the stretch of valley between Willow Creek and Minnie Maud Creek is taken arbitrarily as Upper Desolation Canyon, though it is much less a canyon than a sharply limited valley, and the valley below it to the Roan Cliffs is taken as Desolation Canyon proper.

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[23] Powell, J. W., Exploration of the Colorado River of the West and its tributaries, explored in 1869, 1870, 1871, and 1872, pp. 46-50, 1875.

Near the mouth of Willow Creek much sandstone is present in short lenses. The shale between and around the sandstone lenses is of a sort of mauve color, and the sandstones themselves a coffee-brown. The whole mass has a purple tone when seen in the distance. Near the mouth of Desert Spring Wash the purple beds are replaced in part by gray and yellowish beds. The dip is low, but the replacement is thought to be due to the rising of older beds to river level. A few miles below Desert Spring Wash the walls of the valley are all of gray and yellowish beds of unmistakable Green River aspect. Sandstone is present but only in short lenses, and the bulk of the rock is shale. At Indian Pasture the shaly beds are very conspicuous and the slopes look as if all shale. The change from the purple beds to the gray beds appears to mark the change from the Bridger and Uinta formations to the Green River formation. There seems to be no break. I did not estimate the thickness of the purple-red beds.

Winchester[24] places the base of the Bridger beds some distance above Desert Spring Wash—in fact, beyond the area covered by his map—but he must have had some such distinction in mind as that stated above. The zone of rich oil shale appears at river level about 3 miles above the mouth of Minnie Maud Creek, according to Winchester, and is mapped by him along the walls of the canyon for many miles below, rising southward until high up on the walls it turns to the east and west somewhere near Chandler Creek.

Desolation Canyon.—Desolation Canyon is here considered to extend from Minnie Maud Creek to the Roan Cliffs below the McPherson ranch.

Near Minnie Maud Creek the walls of the canyon appear to be largely shale, gray to yellowish, with only a minor amount of sandstone, but downstream some miles near Tabby Ah Guy Canyon, much more sandstone appears—fine grained, yellow to brown, platy. The sandstone layers in weathered faces are often masked by débris but in clean vertical faces are very evident. Some of the sandstone has probably come in by lateral change from shale, some of it by rising above river level. Near Temple Canyon the lowest beds are nearly all sandstone, yellow and rusty brown, with a minor amount of maroon and greenish-gray shale. Above these sandy beds the shaly gray Green River beds like those of Minnie Maud Canyon appear, but they are so high on the canyon wall that, considering the low dip, it is very unlikely that they could have simply risen. I believe that there has been some lateral change in lithology.

Near the mouth of Jack Creek the rocks for perhaps 1,000 feet above the river are brown sandstone with a minor amount of red and greenish shale. Above these beds are oolitic cream-colored limestone and light shale and sandstone, such as are present in the more typical Green River beds. How much, if any, of the mass of brown sandstone and colored shale are Green River formation and how much Wasatch formation I am unable to say.

Down near the river level at Jack Creek some striking deep-red beds appear. Downstream these red beds near the river become progressively thicker, and there is a fairly sharp plane of division between them and the overlying mass of brown sandstone and colored shale. The distinction is not ideally sharp, as some red coloring occurs in the rocks above, and there is no evidence of any break in sedimentation. The top of the marked red series might well be considered the top of the Wasatch formation, though here, as has been noted at other places in the region by various observers, the position of the boundary between the Wasatch and Green River formations offers ground for wide difference of opinion. These reddish beds make up more and more of the canyon walls downstream until they finally include practically all the rock visible from the river. Near Three Canyon Creek there is much conglomerate of small chert pebbles in the fallen blocks along the river, though I did not see the rock in place. Just below the McPherson ranch at river level appear gray shale, thin brown sandstone, and dark fresh-water limestone crowded with *Viviparus*, *Unio*, and other fossils. Beneath these beds are gray shale with streaks of red and then plain gray shale and brown sandstone. I supposed the red and gray shales associated with the fresh-water limestone to be the base of the Wasatch and the gray shale and brown sandstone beneath them to be the Mesaverde formation of the region. The outcrop of the red beds turns away from the river here to form the Roan Cliffs, and Gray Canyon begins.

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[24] Winchester, D. E., Oil shale of the Uinta Basin, northeastern Utah: U. S. Geol. Survey Bull. 691, pl. 12, 1919.

Gray Canyon.—Gray Canyon is cut in a succession of alternating massive brown sandstone and gray shale—the Mesaverde formation of the region. Coal beds are present in the lower part of this series, but I did not have time to locate any definitely. There is little change in character of the rocks above the end of the canyon, where the outcrops of the sandstones turn off to the east and west to form the Book Cliffs, and the river runs through lowlands of Mancos shale.

COMPARISON OF THE LITHOLOGIC SUCCESSION IN GREEN RIVER VALLEY, SOUTHWESTERN UTAH, AND CENTRAL WYOMING.

The lithologic succession in Green River valley affords an interesting comparison with that of southwestern Utah and that of central Wyoming. In general, the information available would not justify a statement that the units compared are strictly chronologic equivalents, for in the greater parts of the respective stratigraphic columns close paleontologic correlations are not possible. A similarity in the succession of lithologic units may be pointed out, however. The thicknesses of the individual lithologic units compared with one another may differ greatly, owing to differences in the length of the time interval represented by the units compared or to differences in the contemporaneous rate of deposition in the respective areas or to both causes at once.

It has seemed the best method to make such a comparison by arranging the names in current use in three vertical columns with horizontal lines including the units compared and with such comment as may be made appended as notes.

Comparison of the series of lithologic units recognized in Green River valley with those in southwestern Utah and central Wyoming.

<table>
<tr><th>Age.</th><th>Southwestern Utah.</th><th>Green River valley.</th><th colspan="2">Central Wyoming.</th><th>Note.</th></tr>
<tr><td rowspan="3">Tertiary (Eocene).</td><td rowspan="3">Pink Cliff series of Dutton.</td><td>Uinta formation.
Bridger formation.</td><td colspan="2">Uinta formation.
Bridger formation.</td><td rowspan="3">(a)</td></tr>
<tr><td>Green River formation.</td><td rowspan="2">Wasatch formation.</td><td>Wind River formation.</td></tr>
<tr><td>Wasatch formation.</td><td></td></tr>
<tr><td></td><td rowspan="2"></td><td>"Post-Laramie" formation.</td><td colspan="2">Fort Union formation.</td><td rowspan="2">(b)</td></tr>
<tr><td>Tertiary?</td><td>"Laramie" formation.</td><td colspan="2">Lance formation.</td></tr>
<tr><td rowspan="5">Cretaceous.</td><td rowspan="4">Shales and sandstones variously named.[e]</td><td>Lewis shale.</td><td colspan="2">Lewis shale.</td><td>(c)</td></tr>
<tr><td>Mesaverde formation.</td><td colspan="2">Mesaverde formation.</td><td>(d)</td></tr>
<tr><td>Hilliard shale.</td><td colspan="2">Steele shale.
Niobrara formation.
Carlile shale.</td><td></td></tr>
<tr><td>Frontier formation of Schultz.</td><td colspan="2">Frontier formation.</td><td>(f)</td></tr>
<tr><td></td><td>Aspen shale of Schultz.</td><td colspan="2">Mowry shale.
Thermopolis shale.</td><td>(g)</td></tr>
</table>

(See footnotes on pp. 48, 49.)

Comparison of the series of lithologic units recognized in Green River valley with those in southwestern Utah and central Wyoming—Continued.

Age.	Southwestern Utah.		Green River valley.		Central Wyoming.	Note.
Cretaceous. Cretaceous?	Sandstone. Variegated shale.		Beckwith formation of Schultz.	Dakota(?) formation. Morrison formation.	Cloverly formation. Morrison formation.	(h)
Jurassic.	Marine Upper Jurassic.		Twin Creek limestone of Schultz.		Sundance formation.	(i)
	White Cliff sandstone. Vermilion Cliff sandstone.		Nugget sandstone of Schultz.			
Triassic.	Chinle formation. Shinarump conglomerate.		Ankareh shale of Schultz.		Jelm formation.	(j)
	Moenkopi formation.		Thaynes(?) formation of Schultz. Woodside shale of Schultz.		Chugwater formation.	(k)
Permian.	Kaibab limestone. Coconino sandstone. Hermit shale.		Park City formation.		Phosphoria formation.	(l)
Pennsylvanian.	Supai formation.				Absent(?).	
			Weber sandstone.		Tensleep sandstone.	(m)
			Pennsylvanian limestone.		Amsden formation.	(n)
Mississippian.	Redwall limestone.		Mississippian limestone.		Madison limestone.	
Cambrian.	Tonto group.	Muav limestone.	Lodore formation.	(?)	Gallatin limestone.	(o)
		Bright Angel shale.		Shale.	Gros Ventre shale.	
		Tapeats sandstone.		Sandstone.	Flathead quartzite.	
Pre-Cambrian.	Pre-Cambrian.		"Uinta formation."		Pre-Cambrian.	(p)

[a] The exact equivalent in time of the Pink Cliff series of Dutton is uncertain, but it probably represents some part of the Wasatch formation with possibly some later beds. The Green River formation and the Wind River have little in common except stratigraphic position; it is also probable that the Wasatch and Wind River formations are in part contemporary.

[b] The "post-Laramie" formation and the Fort Union formation, besides having a similar stratigraphic position, contain the Fort Union flora. The "Laramie" formation contains the Laramie flora and the Lance formation the Fort Union flora and are supposed on that ground to differ in age. Beds older than Dutton's Pink Cliff series and younger than Cretaceous are not known in southwestern Utah.

[c] The Lewis shale is a somewhat doubtful unit on Green River. There is no well-defined shale unit between the Wasatch beds of the Roan Cliffs and the Mesaverde forma-

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tion of the Book Cliffs, south of the Uinta Mountains, that could be called Lewis shale. North of the mountains such a unit is mentioned by Gale (U. S. Geol. Survey Bull. 341, p. 310, 1909), and by Schultz (U. S. Geol. Survey Bull. 702, fig. 3, 1920), but no description is given. A correlation of the Lewis shale of the Green River region with that of central Wyoming, and of either with the typical Lewis shale in southwestern Colorado is simply a loose grouping of large shale units of upper Montana age and does not imply identity in time of deposition.

[d] It is not known that the Mesaverde formation of the Book Cliffs occupies the same time interval as the Mesaverde formation north of the Uinta Mountains, nor that either is the same as the Mesaverde formation of central Wyoming or of the typical region in southwestern Colorado. This name, like Lewis, has been loosely used and is made to apply practically to any coal-bearing formation within the Montana group.

[e] The Upper Cretaceous deposits of southern Utah are variable in constitution and have been classified differently by different geologists. Much still remains to be learned, and I do not venture to make detailed correlations. There are beds that in a loose way might be called Frontier, others that might be called Mesaverde, and still others that may require other names.

[f] The Frontier formation of the Green River region is a thin sandstone unit very low in the Colorado group. It can hardly be really the same as the much thicker Frontier formation of other areas except under the loose application of the name to any sandy unit in the lower part of the Colorado group.

[g] The Aspen shale on Green River has exactly the lithologic character of the Mowry shale of Wyoming but is very thin and rests almost directly on the preceding sandstone (Dakota?) without any suggestion of an intervening shale like the Thermopolis shale.

[h] The Beckwith formation as delimited by Schultz on Green River contains as its upper member a conglomeratic sandstone that would certainly be mapped as Cloverly formation in Wyoming or Dakota sandstone in Colorado. Whether it is equivalent only to the Dakota sandstone proper or contains also, like the Cloverly formation, beds of probable Lower Cretaceous age, can not be determined in the absence of fossils. The Beckwith beneath this upper sandstone contains three members which together seem to me to be the Morrison formation of Colorado and Wyoming. Schultz offers two different correlations for his Beckwith formation. In one (U. S. Geol. Survey Bull. 702, tables opposite pp. 36 and 82, 1920) he indicates that the Dakota sandstone and Cloverly formation are both probably absent and that the Beckwith formation is all Morrison in age. In the second (idem, pp. 75-77) he expresses the belief that the upper sandstone is equivalent to the Dakota sandstone of some regions and upper Cloverly of others, that the upper shale and middle conglomerate are equivalent to the middle and lower parts of the Cloverly formation, and that the lower shale alone is Morrison. The position of the dinosaur fauna near Jensen and the lithology of the Cloverly formation, so far as I know it, are both against the correlation of the two middle members with the Cloverly formation. It seems also very doubtful to me whether the Beckwith formation of the Green River region is really comparable to the beds to which the name Beckwith is applied farther west in Utah and in Idaho.

[i] W. T. Lee, in a paper now awaiting publication, has adduced abundant evidence to indicate that the Sundance formation of Wyoming, as usually defined, contains in the lower part the equivalent of the Nugget sandstone of the Green River region and of the thick Jurassic sandstone unit of southern Utah believed to include the White Cliff and Vermilion Cliff sandstones. Some writers on Wyoming stratigraphy have included the sandstone in the upper part of the Chugwater formation, but its structural relations ally it more with the overlying than the underlying beds. The Twin Creek limestone of the Green River region is the lithologic and faunal equivalent of the calcareous beds in the upper part of the Sundance. It is very likely that the Twin Creek formation of the Green River region is equivalent to only a small part of the beds to which the name was originally applied. No evidence of any other marine Jurassic formation than the Sundance was observed on Green River.

[j] The correlation suggested by stratigraphic position and structural relations between the Shinarump and Chinle formations, the Ankareh shale of Schultz, and the Jelm formation is largely conjectural. All three are separated from the preceding beds by an unconformity. The Shinarump is regarded as probably Upper Triassic; the Chinle and Jelm contain vertebrate remains of Upper Triassic age; the Ankareh formation in the typical region contains in the lower part marine invertebrates of Lower Triassic age. Whether the Ankareh formation of the Green River region is the same as the typical Ankareh may well be questioned.

[k] A correlation of the Moenkopi formation and the Woodside and Thaynes (?) formations of the Green River valley rests on the assumption that the latter beds are really the equivalent of the marine Lower Triassic formations of the same names that occur in the western Uinta region. It seems to me that the assumption is very probably valid, at least in a broad sense, even though continuous tracing between the two regions is not possible. The relation of the Chugwater formation to those just named is more doubtful, though the presence of a marine limestone in the upper part of the Chugwater is difficult to account for except as an eastward extension of the marine Lower Triassic strata. Another point of difference is that the Moenkopi formation is unconformable on the preceding beds, whereas the Woodside and Chugwater formations appear to be conformable.

[l] The equivalence of the Kaibab limestone, Coconino sandstone, and Hermit shale on the one hand and the Park City formation on the other is not supported by direct evidence. The Coconino and Hermit are placed in the Permian on the basis of fossil plants in the Hermit formation and an unconformity beneath it. The Kaibab limestone has a marine fauna of Permian age, and so has the Park City formation, in its upper (Phosphoria) part, but there are very few species in common. It is possible that the upper (Phosphoria) part of the Park City formation may be entirely later than the Kaibab limestone, though still Permian, as the Kaibab is followed by an unconformity and the upper part of the Park City is

believed to be conformable with the succeeding beds. An unconformity is known in places in southeastern Idaho at the base of the Phosphoria formation.

[m] The Tensleep sandstone, Weber sandstone, and Supai formation are somewhat variable sandy formations that in some phases are very much alike and in others quite different. They are assigned to the late Pennsylvanian (Supai, possibly also including Permian) and probably do not differ greatly in age.

[n] The Redwall limestone, as originally defined from its occurence in northern Arizona, contained beds of both Pennsylvanian and Mississippian age, but in recent classifications the Pennsylvanian part has been added to the Supai formation. In southern Utah a considerable thickness of calcareous strata beneath the sandy beds assigned to the Supai formation contains Pennsylvanian fossils. It is possible also that there are in Green River valley beds of upper Mississippian age, which in Wyoming in places occur in the lower part of the Amsden formation and above the Madison limestone (lower Mississippian).

[o] There is no specific evidence for correlating the Lodore formation with either the Tonto group or the Flathead, Gros Ventre, and Gallatin formations of central Wyoming. All three have a sandstone at the base followed by shales, the gross lithologic features of which are similar. If there is any limestone in the upper part of the Lodore formation, its analogy to the Tonto and Deadwood would be complete. In the field I considered any limestone beds to belong to the overlying Carboniferous, but I may have been mistaken.

[p] There is no specific evidence to show that the "Uinta formation" is Cambrian nor that it is pre-Cambrian.

○

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THE EVOLUTION AND DISINTEGRATION OF MATTER

BY

FRANK WIGGLESWORTH CLARKE

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THE EVOLUTION AND DISINTEGRATION OF MATTER.

By Frank Wigglesworth Clarke.

INTRODUCTION.

In any attempt to study the evolution of matter it is necessary to begin with its simplest known forms, the so-called chemical elements. During a great part of the nineteenth century many philosophical chemists held a vague belief that these elements were not distinct entities but manifestations of one primal substance—the protyle, as it is sometimes called. Other chemists, more conservative, looked askance at all such speculations and held fast to what they regarded as established facts. To them an element was something distinct from other kinds of matter, a substance which could neither be decomposed nor transmuted into anything else. This belief, however, was based entirely upon negative evidence—the inadequacy of our existing resources to produce such sweeping changes. Many important facts were ignored, and especially the fact that the elements are connected by very intimate relations, such as are best shown in the periodic law of Mendeléef, who, from gaps in his table of atomic weights, predicted the existence of three unknown metals, which have since been discovered. For these metals, scandium, gallium, and germanium, he foretold not only their atomic weights but also their most characteristic physical properties and the sort of compounds that each one would form. His prophecies have been verified in every essential particular. One obvious conclusion was soon drawn from Mendeléef's "law," although he was too cautious to admit it, namely, that the chemical elements must have had some community of origin. The philosophical speculations as to their nature were fully justified.

In 1873 I ventured to publish the suggestion that the evolution of planets from nebulae was accompanied by an evolution of the chemical elements.[1] The validity of the nebular hypothesis was assumed, and the progressive chemical complexity of the heavenly bodies gave my argument its plausibility. The nebulae are chemically simple, the hotter stars more complex, the cooler stars and the Sun still more so, and the solid Earth the most complicated of all. The evidence for this statement was found in the spectroscopic researches of Huggins and Secchi, which seemed to me to be conclusive, although defective in one respect: instead of helium in the nebulae they reported nitrogen, for helium was yet to be discovered. This defect, however, did not invalidate my conclusions, which were promptly denounced as heretical but which have since been accepted as quite orthodox. Nearly a year later Lockyer[2] put forth an analogous suggestion, based upon evidence of the same sort but starting from the other end. That is, he assumed that in the hotter stars the elements were dissociated, and his suggestion was received with a good deal of favor. As to the origin of the dissociated elements he had nothing to say. That the elements are really decomposable was the substance of his suggestion, which he followed up in detail in his later publications.

With the discovery of radioactivity by Becquerel and of radium by Madame Curie a new era in chemistry began. It was at once found that at least some of the elements were really unstable; and the evolution of helium from radium, discovered by Ramsay and Soddy, made the evidence complete. A derivation of one element from another had actually been observed.

These discoveries opened a new field of research; and it was soon found that the elements at the top of the atomic-weight scale, namely, uranium and thorium, are spontaneously but slowly decaying, yielding more than thirty new substances which differ widely in stability. To each one a half-life period is assigned, some of them measured in thousands of years, others in fractions of a second. Among these substances are two new varieties of lead—one derived from uranium, the other from thorium—which chemically are not distinguishable from ordinary or normal lead except by differences in their atomic weight and their specific gravity. The lead from thorium has an atomic weight about a unit higher and that from uranium about a unit lower than the atomic weight of normal lead. To this class of facts I shall recur later, as evidence in support of my arguments. That chemical elements can decay is the essential fact to be remembered.

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[1] Clarke, F. W., Evolution and the spectroscope: Pop. Sci. Monthly, January, 1873.

[2] Lockyer, J. N., Roy. Soc. Proc., vol. 21, p. 513; paper dated Nov. 20, 1873.

That the chemical elements were formed by a process of evolution from the simplest forms of matter can hardly be doubted now, but the process is not yet ended. They were developed at high temperatures; but when a certain stage was reached in the cooling mass they began to combine with one another to form the new class of substances which are known as compounds. These substances obviously represent an advanced degree of complexity, with corresponding instability; and with varying conditions both combination and decomposition, such as are reproducible by human agencies, constantly occur. By this extension of the evolutionary process the solid Earth was built up, but in principle the process is the same throughout. From the formation of the first elements to the chemical changes now taking place upon the Earth there is no real interruption. One line of progress has been followed until a maximum of natural complexity and instability is reached in the organic compounds that form the basis of all physical life, whether vegetable or animal. The same fundamental matter, governed by the same fundamental laws, appears from beginning to end of the evolutionary process.

THE EVOLUTION OF THE CHEMICAL ELEMENTS.

In any attempt to discuss the evolution of the chemical elements we have for guidance some facts and many analogies. That the most complex elements are unstable we have already seen, and it is suspected that all the others follow the same rule. Potassium and rubidium are feebly radioactive, a property which is an evidence of instability, and other confirmatory evidence will be cited later. Stability, however, is a relative term, and a substance that is stable under certain conditions becomes unstable under others. The prime factors that determine external stability are temperature, pressure, and chemical environment. For example, some compounds that are stable in anhydrous surroundings are decomposed in presence of water. Calcium carbonate, under ordinary conditions, is divided at high temperatures into carbon dioxide and lime, but heated in a steel bomb it not only remains undecomposed but may even be melted, to form upon cooling a crystalline marble. Examples like this might be multiplied indefinitely. As a rule stability diminishes with increasing temperature but is favored by increased pressure. We may also assume that the more symmetrical an atom or compound is the more stable it is likely to be.

Now, to return to our main problem, was the evolution of the elements a regular progression, such as might be represented by a smooth curve or a straight line; or was it irregular and quite independent of their order in the scale of atomic weights? To answer this question we must try to imagine what happened in the development of the larger masses, the nebulae and the stars. On this subject there is a plausible hypothesis which has been favored by many astronomers—namely, that the nebula at first was relatively cool, that the temperature gradually rose to that of the hottest stars and then regularly declined to that of the end product of the series, the solid planet. A gaseous mass, contracting under the influence of gravitation, became warmer; at its center, where the pressure was greatest, the increasing condensation generated still higher degrees of temperature, until a luminous nucleus was formed. As condensation went on with increasing intensities of pressure, the temperature continued to rise until the heat generated by compression was less than that lost by radiation into space, when cooling began. Although this hypothesis, in its crude form, is not universally accepted, it nevertheless gives a fair conception of that part of the evidence with which we are now concerned. The process of evolution from cool to hot and then to cool again is fairly outlined. The nucleus of the original nebula has its modern representative in the Sun.

In all the foregoing discussion it has been tacitly assumed that the nebula from which the solar system was developed was similar in all essential respects to the planetary nebulae. The latter, as shown by their spectra, consist mainly of hydrogen, helium, and nebulium, with slight traces in some of them of carbon, nitrogen, and perhaps other elements. Nebulium is known only from its lines in the spectrum, and its atomic weight has been estimated by Fabry and Buisson as 2.7, placing it between hydrogen and helium. In any further study of relations between the atomic weights of the elements, nebulium must be taken into account, and perhaps also coronium, so called from its lines in the spectrum of the solar corona. From its position in the corona it is assumed to be lighter than hydrogen and so would seem to be an even more primitive element. That possibility can not be considered here; we must limit ourselves to the conditions actually seen in the nebulae. No assumption is made as to the possible ancestry of the nebular elements; they are the visible beginnings.

Passing from the nebulae to the stars and finally to the planets, the course of evolution has been one of uninterrupted gradations. There are no sharp lines of demarcation between one class and another. As for the elements their evolution has been admirably summarized by Campbell[3] in his lectures on the evolution of the stars. Without literal quotation and accepting the Harvard classification of the stars, I may briefly outline Campbell's summary as follows: After the gaseous nebulae there are first the blue stars of classes A and B. In class B, known as the helium stars, the hydrogen and helium lines are conspicuous, and in their later stages silicon, oxygen, and nitrogen are represented by a few absorption lines. In class A the hydrogen lines are the most prominent, and helium has nearly disappeared. Lines of magnesium and calcium are also conspicuous, and those of iron and titanium are beginning to appear.

In the spectra of stars of class F, the bluish-yellow stars, the metallic lines increase rapidly in prominence; and in those of the yellow stars of class G they appear in great number. Hydrogen is much less conspicuous. In the spectra of the reddish-yellow stars of class K, which are weak in violet light, the metallic lines are more evident, and still more in those of the red stars of class M, in which the spectra also show absorption bands attributed to titanium oxide. In the spectra of the very red stars of class N the violet end of the spectrum is almost entirely lacking, the metallic absorption is very strong, and bands representing carbon oxides are conspicuous.

Such, in brief, was the probable course of elemental evolution in the passage from a gaseous nebula to the coolest and oldest stars. It is not necessary for my purpose to go more into detail on this phase of my subject. The literature relative to solar and stellar spectra is very extensive and is steadily increasing in volume. It involves many questions that I can not attempt to consider, even if I felt myself competent to do so. That the evolution of the elements has actually taken place seems to be established, and I must limit myself to some of the chemical problems that are suggested by it.

Now, it is easy to see that in the process of evolution from nebula to Sun an orderly development of the elements could hardly have been possible. With changing pressure, changing temperature, and changing environment all the conditions required for a regular progression according to the order of the atomic weights were lacking. In the hotter stars only the simplest and most stable elements were formed, and these in the greatest abundance. We have already seen that magnesium, calcium, titanium, and iron were among the earliest to appear, and that the others, between helium (atomic weight 4) and iron, either came later or were developed at first in much smaller quantities. As cooling went on more and more elements were generated, and in the Sun all the possible elements are presumably present, although only about half of them have been actually detected. It is conceivable that elements of different degrees of stability may have been formed simultaneously, one in that part of the cooling mass where the temperature and pressure were highest, another farther away from the center, under less rigorous conditions. This suggestion, however, is something which can not be proved. If the three nebular elements were the raw material from which the other elements were built, their relative amounts must have been continually changing, so that as each new element appeared a new environment was established for all that followed. At some time early in the course of evolution nebulium seems to have vanished, for its lines do not appear in the spectrum of any true star. Was it completely absorbed in building other elements? The question is easy to ask but very difficult to answer.

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[3] Campbell, W. W., Pop. Sci. Monthly, vol. 87, p. 209, 1915; Sci. Monthly, vol. 1, pp. 1, 177, 238, 1915.

That the cooling of a star made the formation of the less stable elements possible has already been assumed. But was the rate of cooling uniform, or was it subject to fluctuations? To answer this question we must bear in mind the clear distinction between atoms and molecules, for here the elements as we know them differ widely. Some molecules, like those of zinc, cadmium, mercury, and the inert gases of the helium group, are monatomic. Hydrogen, nitrogen, oxygen, chlorine, bromine, and iodine are diatomic. Phosphorus and arsenic are tetratomic, and so on. For most of the elements we lack the positive information which we have for those just named. In ordinary chemical reactions the complex molecules are easily decomposed, and at high temperatures also decomposition is possible. The molecule of iodine, for example, is dissociated into its atoms at about 1,700° C., a temperature much lower than that of even the coolest stars. In the hotter stars all the elements present are probably in the atomic state, a considerable fall of temperature must take place before even diatomic molecules can be formed, and they may be regarded as a very primitive order of compounds. In the Sun and the cooler stars compounds in the ordinary sense of the term begin to appear and certain obvious consequences follow.

Whenever two or more free atoms unite to form a chemical compound heat is given out; and in most such unions, as in the formation of water from its elements, condensation has also its thermal value. I must here emphasize my use of the expression "free atoms," for they alone exist in the hotter stars. Such unions are rarely recognized in laboratory experiments, which deal not with direct combinations but nearly always with reactions. The heat of a reaction, which is usually called the heat of formation of a compound, is really the algebraic sum of three or more terms, some of which are positive and some negative. A reaction may be endothermic when the minus terms are in excess, as in the formation of hydriodic acid from its elements. Here the decomposition of the hydrogen and iodine molecules precedes the union of the momentarily free atoms.

In the evolution of the elements we have, then, first the formation of individual atoms, and as cooling goes on their union into diatomic and polyatomic molecules becomes possible. Heat is given out, and the rate of cooling must be somewhat retarded. Whether the retardation is great or small it is impossible to say; but some increase of temperature, even if it is very slight, may fairly be assumed. In short, the rate at which a star cools is in all probability subject to fluctuations, which may influence the development of the more complex and less stable elements. When compounds, as we understand them, begin to be formed, the heating effect is likely to be relatively larger. The cooling of our Sun is almost certainly subject to this sort of retardation, and so its existence as a heat-giving luminary may be considerably prolonged. Heat of chemical origin, with its attendant condensations, must be taken into account in any serious attempt to discover the sources of solar energy. The formation of molecular from atomic hydrogen would alone give out a vast amount of heat, about 82,000 calories per gram-molecule. The supposed formation of helium from hydrogen need not be considered. The helium of the Sun is probably primordial.

So far we have considered only the astronomical evidence relative to evolution, but that evidence is purely qualitative. For quantitative data we must study the so-called atomic weights and their relations, chemical and physical, with one another. The atomic weights, it must be remembered, are not absolute quantities, for no single atom has ever been directly weighed. They are really the expression of ratios, one element being assumed as a standard, with which the others can be compared, by methods that are so well known that it is not necessary to explain them here. These very elementary considerations are cited now because they are so familiar that they are often unconsciously ignored. If we think of the atomic weights as the combining numbers of the elements—that is, the proportions in which each one unites with others—it may be easier to avoid confusion of ideas.

At least three different standards of atomic weight have actually been in use. In the Berzelian system the atomic weight of oxygen was taken as 100, but that led to figures so large for most of the elements that they were difficult to remember and inconvenient to use. The system was therefore abandoned, and the atomic weight of the lightest element, hydrogen, was assumed as unity, a much more natural and satisfactory plan than that of Berzelius. The hydrogen unit, $H = 1$, was in general acceptance until about 30 years ago, and it is still regarded favorably by many chemists. The only objection to it, at least until recently, was that very few of the atomic weights appeared as whole numbers, and the fractional parts were somewhat annoying. There was therefore a tendency among practical chemists to round the figures off to the nearest integers, for in many kinds of analytical work greater accuracy was not required.

On the hydrogen scale the atomic weight of oxygen is 15.876, or nearly 16, a figure which is the basis of the system of atomic weights now generally used. With $O = 16$ a considerable number of other atomic weights become close approximations to whole numbers and therefore more convenient to handle. That is the principal reason why the oxygen standard has been so commonly accepted by chemists. This reason would be more valid if determinations of atomic weight had been made by direct comparison with oxygen, whereas as a matter of fact comparatively few such determinations have been at all satisfactory. With some exceptions, by far the larger number of the best modern determinations have been indirect, with silver, chlorine, and bromine as intermediaries. This indirection, however, does not imply inaccuracy. The actual measurements are those of ratios. To discuss this subject in detail would take me too far from my main theme.

We have already seen that hydrogen and helium are the two oldest elements of which we have any direct experimental knowledge. They also have the lowest atomic weight and are therefore the simplest. The astronomical and chemical lines of evidence are in complete harmony. Nebulium may be left temporarily out of account. Hydrogen and helium, then, are the two elements with which to begin any detailed study of elemental evolution. The atomic weight of hydrogen, 1.0078, is the starting point, with helium next in order. From these elements all other forms of matter may have been derived. There is much evidence in favor of this suggestion, although anything like absolute proof is lacking and perhaps unattainable.

Of the mechanism of the processes by which the elements were built up we have no positive knowledge. It is, however, in the highest degree probable that they were formed under extremely high temperatures and pressures, such as we can not hope to reproduce experimentally. That the evolution of the elements was accompanied by a progressive condensation is evident; and it is also clear that the contraction from the primal highly attenuated nebula to the solid planet was something enormous—so great that we can form no definite conception of its magnitude.

The two most promising lines of quantitative attack upon the problem of elementary evolution are as follows: One begins with a study of the numerical relations between the atomic weights of the elements, and the other with attempts to determine the structure of the atoms. I cite these in their historical order, which is not necessarily the one of greatest importance. The atomic theory was still in its infancy when in 1815 Prout suggested that all the atomic weights were whole numbers, based upon hydrogen as unity. Hydrogen, then, was the primordial element from which all others were derived. As most of the early determinations of atomic weight were rather crude and many of them close to integers, Prout's hypothesis was quite plausible. As the determinations became more exact it was found that few atomic weights were integral and that many of them differed widely from whole numbers. Prout's hypothesis was therefore set aside, although it has recently been revived upon a different foundation.

Since the time of Prout numberless attempts have been made to trace relationships between the atomic weights, but only a few of them were of any scientific value. The subject was a favorite one for a certain class of speculators, who generally started with preconceived opinions as to what atoms ought to be. Some interesting partial relations were pointed out by competent investigators, but the first advance of general significance was the reconstruction of the entire scheme of atomic weights by Cannizzaro, which brought it into harmony with the law of Avogadro. In this new system the old chemical equivalent of oxygen, O = 8, became O = 16, the present standard of value. Definite relations between the atomic weights now began to appear which previously were unsuspected, and these found expression in the "periodic law" of Mendeléef and the Lothar Meyer curve of atomic volumes. In both generalizations the starting point was the same, and the atomic weights were arranged in the order of increasing magnitude, from hydrogen up to uranium; or, as we can say now, the order of their atomic numbers, an expression which has become significant only within very recent years.

The periodic law, or periodic classification of the elements, is given in the following table. The atomic numbers precede the symbols of the elements, and the atomic weights are given below them. A different placing of the rare-earth metals will be considered later.

Periodic table of the elements.

[The upper numerals in the headings indicate natural groups; the lower numerals (arabic) indicate valencies. The rare-earth elements are inclosed within a thick line.]

0 0	I +1	II +2	III +3	IV +4	V −3–5	VI −2–6	VII −1–7	VIII (a)
	1 H 1.008							
2 He 4.00	**3** Li 6.9	**4** Gl 9.1	**5** B 10.8	**6** C 12.00	**7** N 14.01	**8** O 16.00	**9** F 19.00	
10 Ne 20.2	**11** Na 23.00	**12** Mg 24.32	**13** Al 26.96	**14** Si 28.07	**15** P 31.04	**16** S 32.06	**17** Cl 35.46	
18 A 39.9	**19** K 39.1	**20** Ca 40.07	**21** Sc 45.1	**22** Ti 48.1	**23** V 51.0	**24** Cr 52.0	**25** Mn 54.93	**26** Fe **27** Co **28** Ni 55.85 58.97 58.68
	29 Cu 63.57	**30** Zn 65.37	**31** Ga 70.1	**32** Ge 72.5	**33** As 74.96	**34** Se 79.2	**35** Br 79.92	
36 Kr 82.92	**37** Rb 85.45	**38** Sr 87.83	**39** Y 89.33	**40** Zr 90.6	**41** Cb 93.5	**42** Mo 96.0	**43** —	**44** Ru **45** Rh **46** Pd, 101.7 102.9 106.7
	47 Ag 107.88	**48** Cd 112.40	**49** In 114.8	**50** Sn 118.7	**51** Sb 121.7	**52** Te 127.5	**53** I 126.92	
54 Xe 130.2	**55** Cs 132.81	**56** Ba 137.37	**57** La 139.0	**58** Ce 140.25				
	59 Pr **60** Nd 140.6 144.3	**61** — **62** Sm 150.4	**63** Eu **64** Gd 152.0 157.3	**65** Tb 159.2				
	66 Ds **67** Ho 162.5 163.5	**68** Er **69** Tu 167.7 168.5	**70** Yb **71** Lu 173.5 175	**72** —	**73** Ta 181.5	**74** W 184.0	**75** —	**76** Os **77** Ir **78** Pt 190.9 193.1 195.2
	79 Au 197.2	**80** Hg 200.6	**81** Tl 204.0	**82** Pb 207.2	**83** Bi 209.0	**84**[b]	**85** —	
86 Rn 222.0	**87** —	**88** Ra 226.0	**89**[c]	**90** Th 232.15	**91**[d]	**92** U 238.2		

[a] Valencies diverse

[b] Polonium?

[c] Actinium?

[d] Protoactinium?

The significance of the foregoing table, of which there are many variants, is evident at a glance. The elements in each vertical column are closely allied, forming the natural groups with which all chemists are familiar. The alkaline metals, the series calcium, strontium, and barium, the carbon group, and the halogens are examples of this regularity. In other words, similar elements appear at regular intervals and occupy similar places. If we follow any horizontal line of the table from left to right we find a progressive change of valency, and in both directions we find a systematic variation of properties. Broadly stated, the properties of the elements, chemical and physical, are periodic functions of their atomic weights; and this is the most general expression of the periodic law. At certain points in the table gaps are left, and these are believed to correspond to undiscovered elements. For three of the spaces that were vacant when Mendeléef announced the law he made specific predictions, which, as has already been stated, were verified by the discovery of scandium, gallium, and germanium. Radium and the inert gases, much more recently discovered, all fall into their proper places in the table and give additional emphasis to its validity. Place No. 72 is undoubtedly to be filled by the recently discovered element termed hafnium or celtium, two names which are at present in controversy. The names assigned to Nos. 84, 89, and 91 are provisional only and may not be sustained. The elements corresponding to Nos. 43, 61, 75, 85, and 87 are as yet unknown, although their properties can be predicted with a close approach to certainty.

The periodic table is also very suggestive as regards the chemical relations and modes of occurrence of the elements in nature. In the first place, the members of the same elementary group have similar properties, form similar compounds, and give similar reactions, and because of these conditions they are commonly found in more or less close association. Thus the platinum metals are seldom found apart from one another; chlorine, bromine, and iodine occur under very similar conditions; selenium is found in native sulphur; cadmium is extracted from ores of zinc; and so on through a long list of regularities. The group relations govern many of the associations that are actually observed, although they are modified by the conditions that influence chemical union. Even here, however, regularities are still apparent. In combination unlike elements seek one another, and yet there appears to be a preference for neighbors of approximately equivalent mass. For example, silicon follows aluminum in the scale of atomic weights, and in the crust of the earth silicates of aluminum are far the most abundant minerals. An even more striking example is furnished by the series oxygen, sulphur, selenium, and tellurium. Oxidized compounds of many elements are found in the mineral kingdom, but most of them are compounds of metals of low atomic weight. Above manganese, sulphides are abundant; but selenium and tellurium are more often united with the heavier metals silver, mercury, lead, or bismuth, and tellurium with gold. The elements of high atomic weight seem to seek one another, a tendency which is indicated in many directions, even though it may not be stated in the form of a precise law. The general rule is evident, but its full significance is not so clear.

One phase of the periodic law, equally suggestive with the preceding table, is shown in Lothar Meyer's curve of atomic volumes. When these volumes are plotted against the atomic weights they give a curve that consists of a series of undulations or waves of considerable amplitude. On these waves similar elements occupy similar positions—the alkaline metals at the crests, the heavier metals in the depressions, and the other elements in orderly arrangement between these extremes. The regularities are very striking and continue as far as the elements of the rare-earth group above cerium, where the waves flatten out, until at tantalum the curve becomes normal again. Similar curves can be drawn for other physical properties of the elements, with similar results. Richards,[4] for example, has superimposed upon the curve of atomic volumes curves representing compressibilities, coefficients of cubical expansion, and the reciprocals of the melting points. All four curves are similar in type and show the same periodicity. They are somewhat ragged, but nevertheless they tell the same story. The irregularities are due partly to defective data and partly to the fact that the physical constants were not

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[4] Richards, T. W., Am. Chem. Soc. Jour., vol. 37, p. 1649, 1915.

determined under strictly equivalent conditions. The atomic volumes, which are the ratios between the atomic weights and the specific gravities of the solid elements, are especially in need of revision. The specific gravities of some elements were determined at temperatures relatively near their melting points, those of others at temperatures 1,000 or more degrees below them. It is possible that if all could be determined at points near the absolute zero, or, as an alternative, at points just below the temperature of fusion, a smoother curve might be given.

The curve of atomic volumes, as given in Plate XXII, is reproduced, with the author's permission, from Professor A. W. Stewart's volume "Some physico-chemical themes" (London, 1922). In one respect it is likely to be misleading. The atomic volumes are calculated from the atomic weights, not from the atomic numbers.

In the region of the rare-earth metals, between cerium and tantalum, the regular evolution of the elements seems to have been interrupted, so that a systematic periodicity is no longer evident. These metals all resemble one another very closely and form compounds of similar type. Their normal oxides are all of the form R_2O_3, their chlorides are RCl_3, and so on, and they are therefore to be considered trivalent. Cerium, however, which is a member of this group, also forms a dioxide, and it is therefore possibly quadrivalent, although most of its compounds are of the trivalent type. The earlier elements of the group, which appear in the periodic scheme—namely, scandium, yttrium, and lanthanum—are all normal.

Furthermore, the rare earths occur in nature under similar conditions, they are almost everywhere intimately associated, they are difficult to separate, and their oxides are not easily reducible to metals. These very intimate relations need to be explained, and the curious flattening of the Lothar Meyer curve in the part of the atomic-weight scale which the rare-earth metals occupy gives us a clue to their mode of origin. It is evident that they must have been formed under very similar conditions, which changed but slightly as the atomic weights increased. In other words, the conditions were nearly constant, but not quite, for with absolute constancy there would have been only one element generated instead of at least a dozen.

The two preceding paragraphs lead at once to a very simple hypothesis. In the course of evolution from the hottest to the coolest stars there was probably a period of undeterminable duration when the rate of cooling and condensation was in some unknown way retarded, so that the conditions became nearly uniform. During this period, which was followed by one of increased activity, the elements of the rare-earth group were formed. This hypothesis gives a rational explanation of the known facts concerning these elements and is therefore, despite its speculative feature, legitimate. If it is sound, then the elements of the rare-earth series should appear in the periodic table as prolonging the trivalent group, and not be scattered under other groups to which they can not possibly belong.[5]

One more curiously suggestive relation connecting three distinct groups of elements deserves consideration here. The halogens, F, Cl, Br, I, are strongly electronegative; the alkaline metals, Li, Na, K, Rb, Cs, are strongly electropositive; and these two groups are separated by the inert gases, He, Ne, A, Kr, Xe. So we have the following triads: F, Ne, Na; Cl, A, K; Br, Kr, Rb; I, Xe, Cs. The atomic weights in each triad are consecutive. Another probable triad is incomplete; only He and Li are known. One more electronegative element is needed here, which should be a gas of greater chemical activity than fluorine and of lower atomic weight. Is nebulium, with atomic weight near 2.7, the missing member? If so its chemical activity might account for the nonappearance of its lines in the stellar spectra. Was it used in building other elements? That question I have asked already, but it is not yet answered. Here we enter the realm of pure speculation, the foundations of which are insecure. Speculation is of value only in so far as it is suggestive. The intervention of the inert gases between two groups of great chemical activity is well established, but I must leave its explanation to physicists and mathematicians.

Although the periodic classification of the elements is now thoroughly established, there

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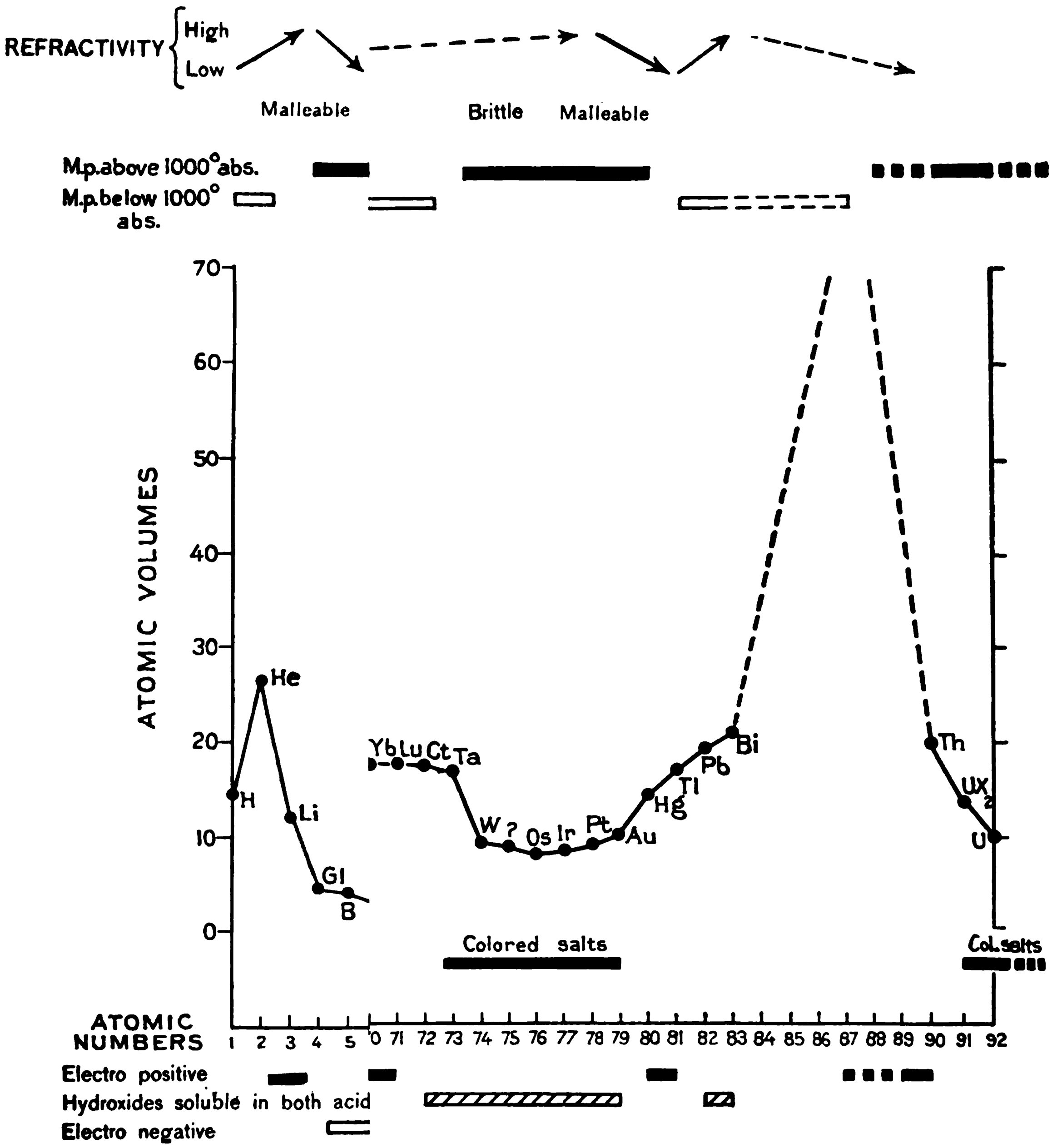
[5] In this mode of placing the rare-earth metals, I find that I have been anticipated by Dr. C. Renz (Zeitschr. anorg. allgem. Chemie, vol. 122, p. 143, 1922). My interpretation of the scheme is, I think, new.


REFRACTIVITY
High
Low
Malleable
Brittle
Malleable
M.p. above 1000° abs.
M.p. below 1000° abs.
ATOMIC VOLUMES
70
60
50
40
30
20
10
0
H
He
Li
Gl
B
Yb
Lu
Ct
Ta
W
?
Os
Ir
Pt
Au
Hg
Tl
Pb
Bi
Th
UX2
U
Colored salts
Col. salts
ATOMIC NUMBERS
1 2 3 4 5 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92
Electro positive
Hydroxides soluble in both acid
Electro negative

are certain details of it that remain to be adequately investigated. The numerical relations between the atomic weights can not at present be discussed with any approach to finality. The problem is complicated by frequent changes—for example, within the last two or three years the atomic weight of scandium has been raised from 44 to 45, that of bismuth from 208 to 209, and that of antimony from 120.2 to 121.77. Recent investigations relative to "isotopes" have thrown doubt upon the definiteness of the atomic weights as they have been actually determined; and until that question is settled experimentally the true numerical relations must remain uncertain. The theoretical atomic weights will be considered later.[6]

Now, using the word in its chemical sense, let us ask: What is an atom? Here many loose reasoners have gone astray and have assumed that because atoms have been found to be decomposable, the atomic theory is overthrown. They seem to regard the etymological meaning of the word as having ultimate significance, but etymology is an unsafe guide in the discussion of scientific problems. The technical significance of a word may be quite unrelated to its etymological history. What, for instance, does the word "chloroform" mean? According to etymology, a green ant!

In brief, the chemical atoms are now known to be complex, ranging from the comparatively simple hydrogen up to the highly complicated and unstable uranium. Each atom is supposed to consist of an electropositive nucleus, attended by one or many electrons of opposite sign. In the hydrogen atom there is one "planetary" electron, in helium two, and so on regularly up to 92 in uranium, at the present summit of the atomic-weight scale. These electrons are also supposed to be, above a certain small number near the beginning of the scale, arranged in rings or perhaps concentric shells around the nuclei. Whether they are revolving about the nuclei, like planets around the Sun, or are relatively at rest is an open question. Models that show the structure of atoms have been constructed, but they are not in complete agreement. The prevalent opinion regards each atom as resembling a miniature solar system, and the term "planetary electrons" is used to distinguish those around the nucleus from some which have found place within it. The mass of an atom is almost entirely concentrated in the nucleus, for it is known that the weight of a single electron is only about $\frac{1}{1800}$ of that of an atom of hydrogen, or 0.00054 on the ordinary scale of atomic weights.

On this foundation Rutherford[7] has erected his scheme of elementary evolution, starting with the hydrogen atom. The nucleus, or "proton," and the single electron are taken as the two fundamental constituents of all matter, whether element or compound, and these units are purely electrical. Prout's hypothesis has come to life again, but in a highly modified form.

The next important step in the study of atomic structure was taken by Moseley,[8] who from measurements of the X-ray spectra of the elements discovered relations which proved that "there is in the atom a fundamental quantity which increases by regular steps as we pass from one element to the next"—that is, the next in the ascending scale of atomic weight—and that "this quantity can only be the charge on the central positive nucleus." That charge increases with increasing atomic weight and so follows the order of the elements upward, or in other words the order of the atomic numbers H 1, He 2, Li 3 . . . Ca 20, Zn 30, and so on up to U 92. These numbers are now regarded by many physicists as of more fundamental importance than the atomic weights from which they were first derived. In the series of atomic numbers, just as in the periodic law, there are gaps that represent undiscovered elements. There is no place in the scheme, however, for nebulium or coronium. The atomic numbers may have to be revised.

Now, without rejecting Moseley's "law," we must admit that the experimental evidence for it is incomplete. The region of the metals of the rare earths needs to be investigated, so as to determine whether their atoms carry electrical charges in the order demanded by the law. Does their anomalous character show itself here? The curious relations of the inert gases, which have already been pointed out, also need explanation. The periodic variations in the physical properties of the elements also seem to require adjustment to the law. The difficulties thus suggested may be more apparent than real, but they should not be ignored.

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[6] For a very complete history of the periodic law, see Venable, F. P., The periodic law, Easton, Pa., 1896—a valuable contribution to the history of chemistry.

[7] Rutherford, Sir Ernest, Nature, vol. 110, p. 182, 1922.

[8] Moseley, H. G. J., Philos. Mag., 6th ser., vol. 26, p. 1024, 1913; vol. 27, p. 703, 1914.

The question has often been asked whether the atomic weights of the elements are definite constants, or merely statistical averages of slightly differing values? The actual determinations were made on masses of material containing millions of atoms, which may or may not be exactly alike but are tacitly assumed to be so. To state the problem in different form, what are the elements as we really know them?

In a remarkable series of experiments Aston [9] has obtained evidence, which he regards as proof, of the complexity of the atomic weights as determined by chemical methods. Powerful positive rays in a magnetic field were driven upon a number of elements, which then gave on photographic plates what he calls their "mass spectra." These spectra show lines corresponding to whole-number atomic weights, which, with some exceptions, represent not the accepted values but some higher and some lower. The new lines, as interpreted by Aston, are due to "isotopes," and the elements yielding them are regarded as mixtures. The subject of isotopes I shall take up in the final section of this paper, where it properly belongs. A few elements gave mass spectra of single lines, which nearly agreed with the accepted atomic weights, and these Aston defines as "simple elements."

From the evidence furnished by the mass spectra Aston concludes that all the true atomic weights, including the isotopes but excepting hydrogen, are whole numbers. This rule he regards as fundamental, although it is based on O = 16 as the standard of values. But this standard was originally adopted as a matter of convenience and had at first no theoretical foundation. It seems, therefore, as if its importance is overrated. Nevertheless we may assume the validity of the rule and see how nearly the atomic weights of some of the "simple elements" conform to it. That is, How far do the real atomic weights diverge from the theoretical whole numbers? The figures are given in the following table:

	Atomic weight.		Divergence, 1 part in—
	Found.	Theoretical.	
Glucinum	9.018	9.0	500
Nitrogen	14.008	14.0	1,750
Aluminum	26.963	27.0	730
Phosphorus	31.04	31.0	773
Sulphur	32.06	32.0	540
Arsenic	74.96	75.0	1,875
Iodine	126.92	127.0	1,588
Caesium	132.81	133.0	700

These divergences are too large to be ascribable to experimental errors. The poorest of the atomic-weight determinations cited above is probably correct within 1 part in 3,000, and that of nitrogen is trustworthy, I think, within 1 part in 10,000. I base my opinion on a careful study of the methods by which each value was determined and especially on their concordance.

That the real and the ideal rarely coincide is well shown in the preceding table, and I venture to cite two well-known examples of such disagreement. Avogadro's law, that equal volumes of gases under equal conditions contain equal numbers of molecules is rigorously applicable only to ideally perfect gases. To the real gases with which we have to deal the law applies approximately and is subject to correction by the two small constants discovered by Van der Waals. The law of electrolytic dissociation is true only for infinitely dilute solutions, and solutions of that kind do not come within our experience. Under working conditions it may be nearly true. Now, if the whole-number rule for the atomic weights is theoretically sound, a supposition which is not yet proved, we may have to assume a distinction between perfect and imperfect elements, and for that assumption there is some justification. Uranium, as we know it, has been slowly decomposing for millions of years, and the uranium that remains is partly decayed. The atomic weight of the normal element as it was before decay began is quite unknown. Thorium offers a similar example, and it is furthermore very doubtful whether any thorium exists that is quite free from ionium of certainly lower atomic weight. In short, the radioactive elements are probably all imperfect in the same way. Are any other elements defective? That we can not say, unless we attempt to define a perfect element. Such an element should be absolutely stable and therefore undecomposable, and only the primal protyle would satisfy these conditions. Hydrogen is the simplest known form of matter, but is there nothing simpler? We do not know.

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[9] Aston, F. W., Isotopes, London, 1922. In this volume Aston gives a complete summary of his own researches, together with much material relative to Rutherford's work, Moseley's law, the periodic system, and related subjects.

In Rutherford's scheme of elementary evolution he uses the hydrogen nucleus with its single electron as a primary unit, and helium, with four protons and two electrons, as a secondary unit. From hydrogen and helium nuclei and electrons the complex nuclei of all the other atoms are supposed to be built up. A system similar to this has been developed by Harkins,[10] who assumes another hypothetical unit of mass 3, composed of three protons and two electrons. This new unit may be equivalent to nebulium, but that is by no means certain. The system, however, works well and brings out some interesting relations between the atomic weights, which may be partly real and partly coincidental. Rutherford seems to neglect nebulium, and neither he nor Harkins takes into account coronium, of unknown atomic weight. Its possible importance, however, ought not to be ignored. Coronium surely exists and must play some part in the evolution of matter. In Nicholson's scheme of elemental evolution[11] coronium, nebulium, and a hypothetical protofluorine are utilized and given atomic weights. That of coronium is assumed to be a little more than half that of hydrogen.

So far the views of Rutherford and Harkins are in essential harmony with the astronomical evidence. Hydrogen and helium are two primary units from which other elements were developed, but in the electrical theory an assumption is made to which an alternative hypothesis is possible. The helium nucleus is supposed to be built up from four hydrogen nuclei or protons. But He = 4, and H = 1.0078; so that 4H is really 4.0312, or slightly less if the loss of two electrons is deducted. A loss of mass in forming helium is therefore assumed and is explained by an electromagnetic theory of "packing." For this explanation, which is not very clear, I must refer to the publications of Rutherford and Aston already cited.

Suppose now that helium instead of being a quasi polymer of hydrogen is really an independent entity of mass 4. This supposition may not be in complete agreement with the electrical theory of matter as that is now formulated, but it is sustained by some evidence. Hydrogen is chemically active, helium is inert, and it is not easy to see how four atoms of the one could coalesce to form an atom of the other. In the nebulae the two elements appear to be widely separated, with no suggestion of any other relation between them than that of a possible common ancestor. Furthermore, the alpha ray of radioactive transformations is an atom of helium, which shows no sign of further decomposition. A priori the new hypothesis is just as plausible as the other, although neither is completely proved. That the alleged loss of mass is not a necessary assumption seems to be clear. In the formation of compounds there is no indication of any "packing effect," although there may be very great condensation.

It is in the highest degree probable that hydrogen and helium are two fundamental elements in the evolution of matter. But nebulium should be considered with them as having some part, if only a subordinate one, in the evolutionary system. From the position of its lines in the spectrum of the great nebula of Orion, Fabry and Buisson, by interferometer measurements, found its atomic weight to be 2.7, or almost exactly $2\frac{2}{3}$. Now, the atomic weights of several other elements, taken as whole numbers, are even multiples of this figure and also of the atomic weight of helium.

From a much larger list I select the following atomic weights for comparison with that of nebulium and with one another; Helium, 4; oxygen, 16; magnesium, 24; sulphur, 32; calcium, 40; titanium, 48; iron, 56. Five of these elements, it will be remembered, are those which appear earliest in the hotter stars. Now, with nebulium (Nm) = $2\frac{2}{3}$, the comparison is as follows:

3 Nm = 8 = 2He
6 Nm = 16 = 4He = O
9 Nm = 24 = 6He
12 Nm = 32 = 8He = 2 O
15 Nm = 40 = 10He
18 Nm = 48 = 12He = 3 O
21 Nm = 56 = 14He

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[10] Harkins, W. D., Phys. Rev., 2d ser., vol. 15, pp. 73, 141, 1920.

[11] Nicholson, J. W., Philos. Mag., 6th ser., vol. 22, p. 864, 1911. Coronium and nebulium are also taken into account by Rydberg (Jour. chim. phys., vol. 12, p. 585, 1914).

Regarded superficially the foregoing figures are very suggestive, but they must not be taken too seriously. They may, perhaps, express approximate relations, and they show that nebulium deserves consideration in any scheme of atom building. It is, however, an unruly element, for it disturbs the order of atomic numbers, and its atomic weight is not integral. The latter irregularity is not serious, for five of the elements in the table have atomic weights that diverge appreciably from whole numbers. Whether the divergences indicate mixtures of isotopes remains to be seen. The table as it stands is an excellent example of the ease with which the theorist can find relations between the atomic weights if he is only allowed to take a few little liberties with the facts.

Two other sets of figures approximating atomic weights are worth citing here. Whole numbers are assumed, and the symbols represent the atomic weights:

$$\mathrm{Fe}=2\mathrm{Si}=4\mathrm{N}=8\mathrm{Li}=14\mathrm{He}$$
$$\mathrm{Mo}=2\mathrm{Ti}=3\mathrm{S}=4\mathrm{Mg}=6\mathrm{O}=8\mathrm{C}=24\mathrm{He}$$

These relations are very striking, but have they any real significance relative to the evolution of the elements? If we were to arrange 92 integers, taken at random between the atomic weights of hydrogen and uranium, and as nearly as possible equally spaced, should we not be likely to find many numerical relations between them? In short, is not the problem of the atomic weights something more than a mere numerical exercise? This question, I think, needs no answer. If many of the chemical atomic weights are merely "statistical averages" of two or more isotopic values, any attempt to discover exact mathematical relations between them will surely be futile.

Since the discovery of radioactivity atomic genealogists, if I may call them so, have been extremely busy. Their contributions to the literature of the subject are very numerous, and I can not undertake to summarize them here. Some of their publications are worthless, and some are extremely valuable, but nearly all are more or less one-sided, for they lay undue stress upon mathematical or physical or chemical data, and each writer ventures little out of his own special field. Not until all lines of evidence have been brought into convergence can the problem of elementary evolution be solved. The workers in different fields and with different outlooks must learn how to cooperate.

In every attempt that has heretofore been made to explain the evolution of the elements in detail there are difficulties which must be faced. Some of these difficulties have already been considered. The integrity of the atomic weights has been called in question, and the deviation of many of them from whole numbers has not been satisfactorily explained. The theory of atomic numbers is also incomplete, for it makes no allowance for possible elements simpler than hydrogen, or between hydrogen and helium; and it reverses the observed order of three pairs of elements, namely, potassium-argon, nickel-cobalt, and iodine-tellurium. That these reversals are justifiable is by no means certain. The positive evidence should not lightly be set aside.

In the last analysis the problem of elementary evolution seems to be one of equilibria, or, which is much the same thing, of relative stabilities; and the fundamental data are those which relate to atomic structure. On this subject there is as yet no general agreement, but the scheme that has been most favorably received is that developed by Rutherford and his colleagues, to which I have already referred.

At first sight Rutherford's scheme of evolution appears to be very simple and symmetrical, but it is by no means free from difficulties, and some of these lie at its very foundations. The light electron and the massive proton are defined as "atoms of negative and positive electricity"; but what these definitions mean is not clear. As the elements above helium are developed the nuclei or groups of protons become more and more complex, and just how the protons are held together is unexplained. The uranium atom is supposed to carry 92 electrons, and this complexity of structure accounts for the recognized instability of that element, as shown by the constant emission of helium from its nucleus, the very swift alpha rays. Between hydrogen and uranium the elements are arranged in the order of their atomic numbers, which represent not only the number of electrons in each atom but also the net electric charge carried by its nucleus. But what is meant by an electric charge upon an "atom" or cluster of "atoms" of electricity? Is there not something in the proton that is not electrical, which serves as the carrier? These questions I can not attempt to answer. They involve the fundamental hypothesis that matter and electricity are identical, which is certainly not proved.

One more doubtful feature of Rutherford's system remains to be noticed. It is assumed that the progression from the simplest to the most complex element is regular and uninterrupted, step by step. But the irregularity shown by the rare-earth elements in the periodic system seems to have been ignored, and this must be taken into account in any valid scheme of elementary evolution.

In what I have said so far I have not intended to be hypercritical. It seemed necessary to point out some of the difficulties that exist in all the schemes of elementary evolution, for to ignore them is to put obstacles in the way of progress. There is really more to be said in favor of the current theories of atomic structure than can be urged against them. All of them are attempts to interpret evidence, and each one is partly successful. Their agreements are more significant than their differences.

A scientific theory has two sides, one speculative, the other utilitarian. As a mere intellectual exercise it has little importance; its real value is in its ability to classify phenomena, to express their relations, and to point the way to new discoveries. In plain language, Does it work? If the prevailing theory of atomic structure is fundamentally sound it must satisfy these conditions. Hitherto it has been developed almost entirely in its physical and mathematical aspects; its chemical aspects have received too little consideration. It is on the chemical side that the theory is likely to be most severely tested. The complete study of any chemical reaction involves problems that are difficult to solve.

A chemical reaction may be described in a general way as a readjustment of equilibria. Let us consider one of the simplest, the formation of water from its elements as represented by the equation

$$2H_2 + O_2 = 2H_2O$$

Here three stable molecules are broken up, and two new stable molecules are formed; heat is generated, and three gaseous volumes are condensed to two. A further condensation to liquid water follows.

Now, in terms of atomic structure, what does this reaction mean? How was it that three elementary molecules could be disrupted and two new ones formed Each hydrogen atom is supposed to consist of a nucleus with one electron, and each oxygen atom of a nucleus with eight electrons. What are these electrons doing, and what is the nucleus of the new molecule of water? Why does condensation take place, and why is heat emitted? Is the loss of heat due to an arrest of motion of two or more electrons? Moreover, by electrolysis the whole reaction can be reversed and the original equilibria reestablished. These questions are as yet unanswered, and they raise the larger question as to the nature of chemical affinity. If the theory of atomic structure is sound it should ultimately shed some light upon these problems.

Let us go a step further and consider a more complicated case, one of double decomposition. When solutions of barium chloride and sodium sulphate are mixed the following reaction occurs:

$$BaCl_2 + Na_2SO_4 = BaSO_4 + 2NaCl$$

Here we have five kinds of atoms and four different molecules, but three of the molecules are partly dissociated in solution. The barium sulphate, however, is thrown down in solid form, and the reaction is not reversible. All the problems suggested by the simpler reaction appear in this new equation, with others that are equally difficult to answer. What part does water play in this double decomposition? Why is the barium sulphate condensed to a solid from diffused ions in the initial solution? What are all the electrons doing, and what are the nuclei of the four compounds? I suspect that we are a long way from any complete answer to these questions. A theory of atomic structure, to be satisfactory to chemists, must give them some clear conceptions regarding the mechanism of chemical reactions.

Examples like these might be multiplied indefinitely, but all give rise to similar problems. In every case, if we accept the electric theory of matter, we must ask the same questions: What are the electrons doing, and how are the protons held together? If for the moment we confine our attention to the evolution of the atoms, we have also to consider the conditions, external and internal, that determine their relative stability. The external conditions have already been defined; the internal conditions are those of atomic structure, its simplicity or complexity, the symmetry of the atom, and the exact electrical balance between electrons and nuclei. A simple, symmetrical atom is likely to be very stable; a complicated structure implies instability. The terms stable and unstable are of course relative; they have no absolute meaning.

In the study of elementary evolution two basic problems underlie all the others. What is the process, and what are its products? Unfortunately we are unable to reproduce the process artificially. We can not hope to build up elements as they are built up in the stars, for the conditions are too severe for us to meet. We can, however, tear down some of the more complex structures and so get some light upon their genesis. That work is now just beginning, and from it we may reasonably expect to arrive at more definite conclusions. The products of devolution we can study directly, and the two lines of evidence ought ultimately to converge.

I venture now to point out one analogy that may have some significance with regard to the character of the elements. Organic chemistry is defined as the chemistry of carbon compounds, and atoms of carbon, in chains or rings, form the skeleton, or framework, or scaffolding of the whole edifice. May not the elements be built in a similar way with atoms of helium instead of carbon? This suggestion is not altogether new: it is implied in the hydrogen-helium scheme of evolution; but here it would include nebulium as a possible part of the superstructure. It is at least worth testing, although I am not blind to possible difficulties in its detailed application.

In all discussions relative to cosmogony there is a danger of going too fast and too far. That statement holds true in the present discussion. We know that the same elements appear throughout the stellar universe, and we must assume that their evolution was governed by the same fundamental laws of chemistry and physics. But we can not assume that all solar systems are exactly like ours in chemical composition. The parent nebulae may have differed in the relative proportions of their component gases, and the rate of cooling in passing from nebula to star was not necessarily everywhere the same. It is conceivable, therefore, that different solar systems may have generated the elements in somewhat different order, and not invariably in the same relative abundance, but these dissimilarities, if they exist, are probably not very large. To assume that anything like absolute uniformity exists would, however, be quite unwarranted.

Before we pass on to the subject of the evolution of compounds, it seems well to consider briefly a question relative to what may be called scientific utility. A scientific theory, to be useful, must meet the conditions that have been stated in a former paragraph and so prove its value. Such a theory is the atomic theory of Dalton, which is the corner stone of modern chemistry. Even the modern electrical conception of matter is based upon it. Many examples of similar purport might be cited.

It has recently been asserted by high authorities that "a chemical element is defined by its atomic number." How far is this conception sustained by the test of its utility? How far can it be used in dealing with chemical problems? May it not be better to say that a chemical element is defined by the aggregate of all its properties? The theory of atomic numbers covers only part of the ground.

The atomic numbers, it should be remembered, assign to each element its place in the order of ascending atomic magnitude. That is, the atomic weights came first, and the atomic numbers followed. It is now held, however, that the atomic numbers also represent the electric charges carried by the nuclei of the atoms, and the number of electrons belonging to each one. These claims may be valid, but they have not yet been as thoroughly tested as they should be. Will they guide future research and be fruitful in discoveries? That remains to be seen.

In practical utility the atomic weights are far more important than the atomic numbers. They are the fundamental quantities of chemical arithmetic and are in constant use in chemical calculations. To the working chemist they are indispensable. In the calculation of analyses, or of the proportions in which substances shall be taken in order to perform a given quantitative reaction, atomic weights are always, directly or indirectly, employed.

They are expressed in every chemical formula and in every chemical equation, and the atomic numbers can never replace them. The laws of chemical combination are based upon the combining numbers of the elements, and these are the atomic weights. In the periodic table the atomic weights and the atomic numbers both appear; but the periodicity of physical properties is best shown in curves like that of atomic volumes. Such curves show that the physical properties of the elements are periodic functions of the atomic weights. The alleged supremacy of the atomic numbers is by no means established. The usefulness of the atomic weights is independent of the order in which they are arranged.

After all, the physical quantities that are directly related to the atomic numbers are functions of the atomic masses, and so, too, are the atomic numbers.

That the theories of atomic structure which have so far been proposed are not in close agreement has already been pointed out. One partial theory, however, deserves mention here—that of the tetrahedral carbon atom as advanced independently by Van't Hoff and by Le Bel. That theory was framed in order to account for the different optical properties of the two tartaric acids, but it did much more than that. It was the foundation of stereochemistry, a new field of research, which has been wonderfully fruitful in important discoveries. The theory was devised before electrons were known, but it is evidently adjustable to the electronic conception of matter. No such adjustment is needed, however to emphasize its proved efficiency.

NOTE.—For a critical summary of the principal theories of atomic structure see Stewart, A. W., Some physico-chemical themes, pp. 373–397, 1922. See also Webster, D. L., and Page, L., Nat. Research Council Bull. 14, 1921.

THE EVOLUTION OF COMPOUNDS.

It has already been said that the process of evolution is continuous, from the simplest forms of matter to the most complex. Between elements and compounds there is no sharp line of demarcation, and one class shades into the other. In one sense the elements are really composite, primary compounds built up from a few fundamental substances, and they are characterized by great relative stability. They have so far not been formed by any artificial synthesis, and they are not decomposable by any of the ordinary processes of the chemical laboratory. The reported decomposition by means of powerful radiations or by electrical currents of the greatest intensity will be considered in another section of this memoir. Compounds, on the other hand, are formed by the combination of elements, into which they are easily separated and from which many of them can be prepared synthetically. The terms element and compound are used here in their ordinary technical significance and are not subject to any verbal quibbling. The elements form one definite class of substances, the compounds form another, and the chief difference between them is one of stability.

Between the formation of an element and the formation of a compound there is, however, another difference. The first stage of the process was one that required a vast period of time; the second stage is marked by rapidity. The series of elements was slowly formed, and their rate of decay, as shown between uranium and lead, is also relatively slow. The formation and decomposition of compounds, on the other hand, is rapid; and for some compounds the rate is measurable. The distinction is not absolutely definite, for some of the short-lived products of radioactive decay seem to be exceptions to the rule, which in general may be stated as follows: The process of evolution is characterized by progressive acceleration, being slow at first and becoming gradually more and more rapid. Its rate of acceleration may not be uniform, but its general drift is clear. It follows the line from the simplest substances to the most complex. In all vital processes the ease and rapidity with which compounds are formed and developed is evident, and some of these substances are extremely complicated.

Just as an infinite number of words can be formed from the 26 letters of the alphabet, so myriads of compounds can be built up from comparatively few elements. At least a hundred thousand compounds are already known, but by far the greater number of them are artificial products and have no place among the relatively simple substances that are developed in a cooling globe. In that laboratory the possibilities of combination are limited. We have already seen that bands

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of a few compounds, such as the oxides of carbon and possibly cyanogen, have been detected in the spectra of the cooler stars and the Sun, but these compounds are all gaseous. Heavy, solid compounds would probably sink below the reversing layer and not be recognized in the spectrum. Can we decide, with any approach to probability, what solid compounds would be likely to be first formed under the conditions of a cooling globe?

The answer to this question is simple. The most stable compounds would come first, and they are such as appear among the products of the electric furnace. Carbides, silicides, phosphides, borides, and nitrides are all stable at very high temperatures, and such compounds with iron, nickel, or manganese as bases are substances of high specific gravity and would be likely to sink deeply into the cooling mass. At the surface of the Earth and probably throughout the lithosphere they would cease to exist, for water, especially in the form of superheated steam, transforms them into other compounds, such as hydrocarbons, oxides, silicates, phosphates, borates, and salts of ammonium. Water must have been a compound to appear at an early stage in the process of evolution, and it is one of the principal reagents that were and are active in determining the composition of the Earth's crust.

This speculation, which is not extravagant, receives some support from the study of volcanic emanations, of which carbon dioxide and ammonium chloride are common constituents. Hydrocarbons in small amount are also found among volcanic ejectamenta. The existence of boron nitride within the Earth is suggested by the association of boric acid and ammonium compounds in the Tuscan fumaroles and at other well-known localities. Boron nitride is a very stable compound; but when heated in a current of steam it yields boric acid and ammonia. As for silicates and oxides, they are the chief constituents of the lithosphere. The silicates would be easily formed by oxidation of the primary silicides, but only the simpler compounds, such as constitute at least nine-tenths of the present lithosphere, would appear at first. Their crystallization and segregation could take place only in the cooling of a fused magma. On this point their artificial syntheses are conclusive. From such a magma the primitive crust of the Earth was formed.

A variety of processes, some physical and some chemical, must have taken part in the solidification of the planet; but their effects could hardly have been symmetrically distributed. The temperature of the cooling mass was certainly not uniform. Whenever new compounds were formed heat was generated, the local temperature rose, and inequalities of composition were brought about by diffusion. Where the temperature at the surface of the globe was lowest there solidification began. At such points new chemical reactions became possible through contact with the gases and vapors of the primeval atmosphere. Just what the composition of that atmosphere may have been we do not know; but it must have contained oxygen, carbonic acid, and water, three powerful reagents, with possibly some of the stronger acids also.

Throughout the cooling process and indeed throughout the process of evolution from nebula to planet, gravitational energy was at work distributing the various forms of matter according to their density. In the Earth we have a heavy, probably metallic nucleus, surrounded by a zone of the denser silicates grading upward into lighter compounds, and after them a relatively thin shell of sediments and other decomposition products. Then comes the hydrosphere, and surrounding all the atmosphere. These zones are of course not sharply separated but interpenetrate one another to a greater or less extent. Volcanic effusions, for example, break through the sediments, and locally reverse the primary gravitational arrangement, which, after all, is what might be called an irregular regularity. The broad outlines of the process are clearly discernible in spite of local blurring.

This zonal structure of our planet, due to gravitational adjustment, has been of great significance in fixing the conditions upon which terrestrial compounds could be formed. It is commonly supposed that the Earth is analogous to a huge meteorite, having a nucleus consisting principally of nickel-iron with some inclusions of free carbon and a few simple compounds. This supposition will be considered in detail in the next section of this memoir; if it is correct then the nucleus of the

Earth, or centrosphere, is essentially a region of almost no chemical activity. It is protected from the outermost zones of active reagents by the intervening shells of igneous silicate rocks, which are easily modified by aqueous and atmospheric agencies and in less degree by volcanism. To cite two familiar examples of such changes magnesian rocks are converted into talc and serpentine, and feldspathic rocks are kaolinized. In short, on passing from the centrosphere to the surface of the lithosphere, the chemical changes become more and more varied and complex. Through them the sedimentary rocks were formed, and in the later stages of the Earth's history living organisms also played an important part in the production of limestone, dolomite, and marine phosphates. Leaving minor details out of account we may say that the general conditions governing the evolution of natural inorganic compounds seem to be fairly well understood, even though we know very little of the inner mechanism of the many reactions in which combinations and decompositions proceeded simultaneously. In the geologic history of the Earth's crust the more important of the chemical changes are easily traced. The artificial syntheses of many minerals also give us much information upon the problem of inorganic evolution.

At the surface of the Earth, when its crust was sufficiently cool, the evolution of compounds entered upon a new field of activity. Organic compounds were formed, and they furnished the material basis for the evolution of living beings. Organisms, each capable of reproducing its kind, became physically possible. This faculty of reproduction is something that sharply distinguishes living from nonliving matter.

The probability that carbides and nitrides were among the earliest compounds to form in a cooling globe has already been pointed out, and also that these compounds, by hydrolysis, yield hydrocarbons and ammonia. Calcium carbide yields acetylene, which easily polymerizes into benzene, from which a long list of other hydrocarbons can be derived. The carbides of aluminum, glucinum, and manganese give methane, CH_4; those of the rare-earth metals yield mixtures of acetylene, methane, and ethylene, and from some of them liquid and solid hydrocarbons are also derived. From uranium carbide Moissan[12] obtained a mixture of liquids, consisting largely of olefines with some members of the acetylene series and some saturated compounds. Hydrogen is also set free in some of these reactions.[13]

If now, by reactions such as have just been described, hydrocarbons and ammonia were formed from compounds contained in the primitive magma, a first step was probably taken toward preparing the surface of the Earth for the advent of living organisms. From metallic phosphides phosphine, the analogue of ammonia, would be generated, and it would quickly be oxidized, yielding phosphates. Among the substances that appear in volcanic emanations there are hydrogen sulphide, sulphur dioxide, carbonic acid, and hydrochloric acid, compounds which might all be formed simultaneously with the hydrocarbons. Add to these the gases of the atmosphere, and we shall have assembled much of the raw material that is essential to the later upbuilding of organic tissue. But between magma and protoplasm there is a vast gap, which science has not yet bridged. The evolution of compounds has not stopped, but our knowledge of its course is interrupted.

The moment we enter the field of biochemistry we encounter problems of great complexity. Innumerable new compounds appear, especially in the tissues of plants, and some of them are extremely complicated. Many of these compounds, however, can be isolated and analyzed. We can determine their composition and measure their physical properties, but how they were developed in the growing plant is a question that is rarely answered even in part. One group of examples will serve to show how complex the problems really are.

One of the most marvelous of chemical laboratories is contained within the seed capsule of the opium poppy, *Papaver somniferum*. In that small inclosure a juice is secreted which when dried, solidifies to that extremely complicated mixture opium. In opium about thirty different compounds have been identified, including more than twenty distinct alkaloids, of which morphine, $C_{17}H_{19}NO_3$, is the most abundant but not the most complex, although, as we see from its formula, each molecule contains forty atoms. How many protons and how many electrons are there here, and what are they doing?

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[12] Moissan, H., Compt. Rend., vol. 122, p. 1462, 1896. See also Damiens. M. A., Annales de chimie, 9th ser., vol. 10, p. 137, 1918, on the carbides of the cerium group.

[13] For a summary of the literature relating to the inorganic syntheses of hydrocarbons, and especially from the carbides contained in cast iron, see Clarke, F. W., The data of geochemistry, 4th ed.: U. S. Geol. Survey Bull. 695, pp. 730-732, 1920.

But this is not all. The capsule also contains the seeds from which other plants can be grown, and in each plant within a single season this complex of chemical syntheses is begun and completed, and so on generation after generation. The seeds are rich in oil but not in alkaloids; it is at the summit of their growth that these very complicated substances appear.

Suppose now that on this same acre of ground with the poppy are sown the seeds of a dozen or more plants. Each one will be, in a certain sense, a synthetic chemist, working out its own special set of reactions. A tobacco plant will form nicotine, mustard will generate an "oil" rich in sulphur, some species will produce hydrocarbons such as terpenes, while others will specialize in forming sugar or starch or strong acids. All are nourished by the same soil, the same water, and the same atmosphere, but each one breeds true to type and never makes a mistake in its chemistry. Does each seed contain some directive principle that guides its germination and growth? To say that the seeds differ in composition, which is quite true, may give a partial answer to this question; but it does not explain the vital factor, the capacity of each plant to reproduce its kind.

Up to a certain point the evolution of compounds within these different plants follows similar lines. All generate the vegetable fiber that is, so to speak, the fabric of their skeletons, and all produce chlorophyll, the principal coloring matter of their leaves. I use the term chlorophyll in its general sense, although this substance is usually if not always commingled with other compounds of similar character. Here a new reagent becomes of supreme influence—namely, radiant energy, the energy of the Sun's rays. It is only by means of this reagent that chlorophyll can form. Are some of the other syntheses also dependent upon it? Albuminoids and proteids are also produced, and in these colloid substances chemical complexity probably reaches its limit. They are the essential constituents of protoplasm.

In animal matter, which consists almost entirely of proteids, the complexity is even greater than in plants. Plants may contain a much larger number and variety of definite crystallizable compounds, but in animal tissues the proteids predominate, and they are of many different kinds. Into this subject I can not go at length, but I may be permitted to ask one question. Is the morphological or structural increase in complexity from the lowest to the highest forms of life accompanied by a corresponding change in the complexity of chemical constitution? This aspect of evolution has, I think, never been seriously considered, but it surely deserves attention. To show its significance I venture to offer the following illustration, which is based upon an elaborate study of the inorganic matter of marine invertebrates:[14]

In some of the lowest forms of life, as in the diatoms, radiolarians, and siliceous sponges, the skeletal matter consists chiefly of opaline silica, a very simple substance. The stony corals are built up from calcium carbonate, which is slightly more complex. The echinoderm skeletons also contain magnesium carbonate, and the shells of some brachiopods consist mainly of calcium phosphate. The shells of the higher crustaceans, such as the lobster, are still more complicated. With a large proportion of organic matter, proteid in character, they contain both carbonates and phosphates of calcium and magnesium. The progressive increase in complexity is clearly evident. It also appears in the bones of the higher mammals. In them we find organic substances, such as gelatin and fats, but also carbonates of calcium and magnesium, with a very large proportion of calcium fluophosphate. The question that was asked in the preceding paragraph is surely pertinent, and it receives the beginning of an answer here. A complete answer, however, will involve some serious discriminations, and it must also recognize the fact that we are now considering products and not processes. The two fields of investigation must, of course, be studied together, but the distinction between them is clear. A physiological process is a complex of chemical combinations and decompositions, of evolutions and devolutions, and the two sets of phenomena are quite distinct, even though they always appear together. The one is the complement of the other. The physiological processes of the higher animals are surely more complicated than those of lower forms.

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[14] See Clarke, F. W., and Wheeler, W. C., U. S. Geol. Survey Prof. Paper 124, 1922.

For example: In respiration we inhale oxygen and exhale carbonic acid, which is produced by the consumption of organic tissue. The formation and renewal of the tissue is a case of true evolution, to which our question properly relates; the rejected waste or excretory products can for present purposes be disregarded. We are considering the products of growth, not those of decay. The discrimination may sometimes be difficult, but it should never be ignored. The alkaloids of opium, for instance, are waste products and represent the downward path of chemical change. Their citation here, however, serves to illustrate the wonderful complexity of the processes that are involved in the growth of plants.

The formation of any new compound, whether simple or complex, natural or artificial, is an item in the scheme of chemical evolution. Under natural conditions many well-known compounds are incapable of existence; some are destroyed by even moderately high temperatures; others are decomposed by the action of water; and still others, like the fulminates, are easily exploded by percussion or friction. All these inhibitions are evaded or controlled by a skillful chemist, who can regulate temperatures and pressures and can establish for each compound the environment in which it can form. He can also work with pure materials, which are rarely found under natural conditions. The artificial compounds help us to a better understanding of those which exist in nature, and this can easily be shown.

Many of the minerals that form the solid crust of the Earth have been reproduced synthetically by methods equivalent to those followed by nature. The species that are characteristic of the igneous rocks, such as the feldspars, pyroxenes, and olivine, originate in molten magmas, and artificial magmas yield the same compounds. Quartz may be either magmatic or crystallized from aqueous solutions, and both modes of origin can be copied in the chemical laboratory. Artificial limestone is easily prepared, and so too are gypsum and a number of other minerals, all of aqueous origin, that are found in beds of salt. The researches of Van't Hoff and his colleagues upon the Stassfurt salts are especially suggestive. The compounds associated with the salt were not only prepared synthetically, but the temperature at which each one formed was also determined, giving datum points in what has been called a "geological thermometer." Similar temperature relations have been discovered for other minerals, such as the silica group and wollastonite, and they give valuable information as to the conditions under which the rocks containing them were deposited. In short, the chemical processes that took part in terrestrial evolution are being revealed experimentally. The literature of synthetic mineralogy is very voluminous, but these few examples are all that need to be cited here. They serve to illustrate the methods by which some problems of evolution are being solved.

What has been said relative to the syntheses of inorganic compounds also applies, but with serious limitations, in the organic field. Many substances that are found to exist in living organisms have been made artificially, but by methods that are surely not identical with those followed by plant or animal. In life many syntheses are effected simultaneously and rapidly; in the laboratory the conditions are quite different. The chemist starts with pure material and builds his compounds individually and slowly, but his results are nevertheless of great significance, even though they may not be directly applicable to the interpretation of vital phenomena. There is, however, a partial correlation, which is better than none at all.

This is no place for an essay on biochemistry, which may be described as the dynamic side of physiology. All living organisms, considered apart from their psychological relations, are dependent upon a complex of chemical changes, some products of which are utilized and others rejected as waste. In the digestion of food many of these changes have been traced, and a great variety of compounds take part in them. Some of the compounds, especially the proteids, are broken down into simpler forms; and their derivatives are distributed each to its proper place in the organism. The motive power that effects their distribution is thermochemical in origin and is measured in terms of calories. Finally, new proteids are formed, and wasted tissues are regenerated; and this is true chemical evolution. The evolution of the Earth's crust and the evolution of living tissue are parts of the same line of growth from the simplest to the most complicated forms of matter. The line, however, is not straight but one with many branchings.

THE RELATIVE ABUNDANCE OF THE CHEMICAL ELEMENTS.

One of the most obvious facts in chemistry is that some of the elements are very abundant and others extremely rare. It is also easy to see that this distinction is definitely related to the conditions under which the different elements were generated. The simplest and most stable ones were formed at the highest temperatures and in the greatest abundance; the most complex elements appeared last of all and in the smallest quantities. The original nebula was a finite mass of matter, and the scarcer elements represent the material left over after the more common ones had been formed. How far do these conclusions harmonize with the observed facts?

In an attempt to answer this question we must recognize certain limitations. An almost infinitesimal portion of the matter that forms the solar system is all that is available for direct quantitative investigation. Only the Ocean, the atmosphere, and a very thin outer shell of the Earth's crust are accessible to us. As for the Ocean and the atmosphere, their composition is well known; that of the rocky shell is less easily ascertained.

In order to determine the average composition of known terrestrial matter we must first fix the relative proportions of its three components. For this purpose let us assume that the crust of the Earth to a depth of 10 miles is essentially like the average rock of its surface, of the rocks which we know and can analyze. The volume of such a crust, including the mean elevation of the continents above the sea, is 1,633,000,000 cubic miles, with a probable density of about 2.7 to 2.8.

The volume of the Ocean is approximately 302,000,000 cubic miles, although some authorities give slightly higher figures, and its density is a little below 1.03. This is the maximum density found by Dittmar in the water of the great oceans, and its use here makes a liberal allowance for the saline matter, such as beds of salt, that are found in the crust of the Earth. For present purposes they are negligible quantities. If the salts of the Ocean were gathered into one solid block, they would have a volume of at least 4,800,000 cubic miles, or enough to cover the entire United States to a depth of 1.6 miles. The fresh waters of our globe are also negligible, for a quantity equivalent to 1 per cent of the Ocean would cover all the land areas to a depth of 200 feet. Even the mass of Lake Superior becomes relatively insignificant. The mass of the atmosphere, so far as it can be determined, is equivalent to that of 1,268,000 cubic miles of water, the unit of density. Combining these figures, we have for the composition of known terrestrial matter about 93 per cent of solid crust, with 7 per cent for the Ocean. The proportion assignable to the atmosphere is only 0.03 per cent, which may be regarded as a small correction to be applied when needed.[15] We are dealing with the relative abundance of the different forms of matter and not with absolute quantities. Quantitative accuracy is not attainable.

What, now, is the composition of the accessible part of the lithosphere? Neglecting the thin film of organic matter upon its surface, we need only consider two classes of rocks, the igneous and the sedimentary. Metamorphic rocks are merely the result of alterations of one or the other of these two and may be left out of account. Such inclusions as beds of coal or metallic ores are insignificant in quantity as compared with the vast mass of rocks now under consideration, which is, as nearly as can be determined, 95 per cent igneous and 5 per cent sedimentary. The method by which these figures were obtained, together with the average composition of the sediments, I have given elsewhere.[16]

As it is impossible to analyze the 10-mile crust as a whole, we must do as well as we can by the method of sampling—that is, we must take samples of igneous rocks, the parents of the others, from as many different localities as possible, and then average the analyses. Thousands of such analyses have been made for petrologic purposes and are now available for use. The material came from all quarters of the globe, and the analyses that are considered trustworthy have been assembled by H. S. Washington in a monumental volume.[17] From the data given by him 5,159 analyses rated as "superior" have been taken and averaged together, giving a fair conception of the mean composition of the igneous rocks.[18]

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[15] For the details of this computation see Clarke, F. W., The data of geochemistry, 4th ed.: U. S. Geol. Survey Bull. 695, pp. 22-33, 1920.

[16] Idem, pp. 29-32.

Now, omitting details, which can be found in the publications already cited, let us consider the significance of the following averages. The first column of figures gives the mean composition of 5,159 igneous rocks, stated in terms of elements and in percentages. The last column gives the average obtained by including accepted values for the sediments, the ocean, and the atmosphere, or in other words the mean composition of all known terrestrial matter to an assumed depth of 10 miles below sea level.

Average composition of igneous rocks and of all known terrestrial matter.

	1	2
Oxygen	46.41	49.19
Silicon	27.58	25.71
Aluminum	8.08	7.50
Iron	5.08	4.68
Calcium	3.61	3.37
Sodium	2.83	2.61
Potassium	2.58	2.38
Magnesium	2.09	1.94
Titanium	.72	.648
Phosphorus	.157	.142
Hydrogen	.129	.872
Manganese	.124	.108
Chlorine	.096	[a] .228
Carbon	.051	[b] .139
Minor constituents	.463	.473
	100.00	100.000

[a] Oceanic.

[b] In limestone.

These figures show that eight elements form 97.38 per cent of all known terrestrial matter, leaving only 2.62 per cent for all the others. The influence of the Ocean and the atmosphere is very slight, and with a thicker mass of igneous rocks it would be still smaller. In the Earth as a whole the Ocean would amount to only a small fraction of 1 per cent and therefore be negligible.

In many of the published analyses of igneous rocks figures are given showing appreciable but small percentages of some of the scarcer elements. The average amounts are as follows:

Barium	0.081	Nickel	0.031
Sulphur	.080	Fluorine	.030
Chromium	.052	Copper	.010
Zirconium	.051	Lithium	.005
Vanadium	.041	Zinc	.004
Strontium	.034	Lead	.002

Several attempts have been made to determine the composition of the Earth as a whole, all based upon its supposed similarity to a huge meteorite. The mean density of the Earth is nearly double that of its crust, and it behaves like an enormous magnet. Hence the assumption has been made, to which I have already referred, that its central portion is metallic and consists largely of iron. How far is this assumption justifiable?

To answer this question let us begin with the chemical composition of known meteorites. These extraterrestrial bodies are divided into two classes, meteoric stones and meteoric irons, which, however, are not sharply distinct. Nearly all the stony meteorites contain more or less iron, and many of the others contain stone. For instance, the pallasites are masses of iron, with something like the texture of a sponge, in which the cells are filled with nodules of olivine. Again, the meteoric shower that fell at Estherville, Iowa, in 1879, contained masses of stone and many smaller masses of iron. These were all, of course, components of the original meteor. For the average composition of 99 meteoric stones we have the following computation by Merrill.[19] The first column of figures gives the actual average; the second is recalculated to 100 per cent after rejecting the admixed nickel-iron, sulphides, and phosphides.

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[17] Washington, H. S., Chemical analyses of igneous rocks, 1884 to 1913: U. S. Geol. Survey Prof. Paper 99, 1917.

[18] A detailed critical discussion of the method of averaging and the results obtained is to appear in Professional Paper 127 of the Geological Survey, by Clarke and Washington, now in press. An abstract of the averages was published in the Proceedings of the National Academy of Sciences for May, 1922.

[19] Merrill, G. P., Am. Jour. Sci., 4th ser., vol. 27, p. 469, 1909. Another average, by O. C. Farrington, appears in Field Columbian Mus. Pub. 151, 1911. It is in fair agreement with Merrill's.

Average composition of meteoric stones.

	Found.	Recalculated.
Silica	38.98	45.46
Alumina	2.75	3.21
Ferrous oxide	16.54	19.29
Lime	1.77	2.06
Magnesia	23.03	26.86
Soda	.95	1.11
Potassa	.33	.38
Manganese oxide	.56	.65
Chromite	.84	.98
Nickel, including cobalt	1.32	....
Metallic iron	11.61	....
Sulphur	1.85	....
Phosphorus	.11	....
	100.64	100.00

Some of the analyses show small amounts of copper, tin, carbon, etc., which need not be considered here. The average stone is essentially a peridotite and therefore quite different from the average terrestrial rock. A great deficiency in feldspars is evident, and they form nearly 60 per cent of the 10-mile shell of the lithosphere. There is little or no free silica indicated by the figures. That the meteorites were originally in a state of fusion is also clear, for the dominant mineral, olivine, is formed only in that way. The same is true also of the glass, which is a common constituent of meteoric stones.

It is by no means certain that the average given in the foregoing table represents with any accuracy the mean composition of all known meteoric stones, of which many were never analyzed. Even these meteorites form but a trifling fraction of the vast number that must have fallen unseen. Some doubtless fell in the ocean, and others in deserts or forests, never to be found. Nevertheless the average is not without value, when it is considered in relation to other data. As for the individual stones that are represented in the average, they show great differences in composition. A very few, of which Juvinas and Stannern are typical, consist mainly of augite and anorthite, with very little nickel-iron. The Bishopville stone is nearly pure enstatite. These stones are exceptional; in by far the greater number of known falls pyroxenes and olivine are the dominant minerals, with variable proportions of nickel-iron. The transition from stone to iron is very gradual. The very common chromite of meteoric stones is invariably associated with magnesian minerals, iron, and nickel—the same association that is found in terrestrial rocks. Oldhamite, calcium sulphide, is only known as a meteoric mineral; it dissolves in water and rapidly hydrolyzes, therefore it can not long exist except in anhydrous surroundings, and all our igneous rocks contain small amounts of water.

One very small group of meteoric stones deserves to be considered separately—the carbonaceous meteorites. The type and extreme example of these is the one that fell at Orgueil, France, in which Pisani found 13.89 per cent of water plus organic matter, which consisted essentially of hydrocarbons. Such a meteorite could reach the surface of the Earth only under very exceptional conditions. The chances are that its organic matter would be burned soon after it entered the atmosphere, and its stony portion disintegrated and scattered as dust. If so the atmosphere must receive accessions of carbon dioxide that would have a distinct influence upon plant life and would perhaps account, in part at least, for the carbon that is locked up in coal and petroleum. This, I admit, is pure speculation, but not without some plausibility. A cometary origin of these meteors is probable, for hydrocarbons are shown in the spectra of comets, and several instances are known of periodic showers of stars that have followed the paths of periodic comets which have disappeared. Biela's comet is one which after repeated returns is now represented only by a starry shower. We can not, however, assume that all meteors are the remains of comets. There is, as will be seen later, strong evidence to the contrary.

The average composition of meteoric iron is more easily determined than that of meteoric stone. The one consists mainly of an alloy of nickel and iron; the other is a mixture of different silicates. The irons contain, in minor proportions, several other substances, such as troilite, FeS; schreibersite, a phosphide of iron and nickel; daubréelite, $FeCr_2S_4$, the sulphide corresponding to the chromite of meteoric stones; lawrencite, $FeCl_2$; cohenite, $(FeNiCo)_3C$; graphitic carbon; and in the iron of Canyon Diablo, minute diamonds. Diamond is also found in the meteoric stone of Novo Urei. Carborundum, CSi, is also reported by Moissan as present in the Canyon Diablo iron. Nodules of troilite and of graphitic carbon are common, some of them as large as a hen's egg; the other inclusions are diffused in smaller amounts. Of these the lawrencite is in one way the most conspicuous, although it is rarely seen in distinct masses. On exposure to moisture it is hydrolyzed, forming basic chlorides and releasing hydrochloric acid, so that its presence is too often manifested by the tendency of an iron to rust and ultimately to fall to pieces. Everyone who has had much experience in handling collections of meteorites knows how troublesome this obnoxious compound is. It is very difficult to stop its ravages. It is not improbable that much of the chlorine in the ocean came originally from lawrencite. Was the primeval ocean strongly acid? The question is legitimate, even if it can not be definitely answered. Some of the oceanic chlorine is undoubtedly of volcanic origin, and that may have had its source in lawrencite. We do not know the facts but may be permitted to suppose. One thing is certain—namely, that the permanence of a meteoric iron depends upon the amount of ferrous chloride which it contains.

At Ovifak, in Greenland, and at several neighboring localities, native iron is found which was at first thought to be of meteoric origin. It is now known to be terrestrial iron, brought up in some manner from below, together with the basalt in which it is embedded. Some of it is in small grains and some in large masses of several tons in weight, and it resembles meteoric iron in every essential particular. It contains some lawrencite, and also carbon, which is combined with iron, probably as cohenite. The presence of a carbide was proved by George Steiger in the laboratory of the United States Geological Survey. By heating some of the Ovifak iron with ammonium chloride he obtained a mixture of hydrocarbons, both saturated and unsaturated.

For the average composition of meteoric iron and its terrestrial equivalent we now have the following data: First, the average of 318 analyses of meteoric iron, as computed by Farrington[20]; second, the average of 13 analyses of the Greenland iron, cited by Dana.[21] In the analyses of Greenland iron figures for silica and insoluble matter have been rejected as representing impurities taken up from the adjacent rocks.

Average composition of meteoric and native iron.

	Meteoric.	Terrestrial.
Iron	90. 85	92. 53
Nickel	8. 52	2. 20
Cobalt	. 59	. 62
Copper	. 02	. 23
Sulphur	. 04	. 28
Carbon	. 03	1. 78
Phosphorus	. 17	. 21
Chlorine	....	. 06
Chromium	. 01	....
	100. 23	97. 91

These averages, although they differ somewhat, do so no more than individual analyses of meteoric iron. No two irons are precisely alike. The absence of chlorine from the first column of figures merely means that it was not determined, and the same is true with reference to chromium in the second column. Analyses of rocks and minerals differ widely as regards completeness.

In one way the analyses of meteoric irons are likely to be slightly misleading. They represent clean, bright samples of the nickel-iron and take no account of the large inclusions of graphite, troilite, and the more generally diffused ferrous chloride. The composition of the entire mass of an iron would be unlike that of the selected metal, and the inclusions might amount to several per cent. No good estimate can be made of their average quantities. The averages given in the table, therefore, represent only approximate orders of magnitude, but the percentages of the minor constituents are certainly not large.

That the minerals of the meteoric stones were originally in a state of fusion seems to be clear. Was the meteoric iron also molten? This question can be answered in the affirmative, for the following reasons:

In the preceding section of this paper it was shown that carbides and phosphides were among the compounds that would be the earliest to form in a cooling globe. Both carbides and phosphides are found in meteoric iron, and the even more significant sulphides also. Furthermore, troilite and graphitic carbon are often found in large nodules that could hardly have segregated except from a fluid or semifluid mass. The diamonds of the Canyon Diablo iron tell the same story. The artificial diamonds obtained by Moissan were produced by dissolving carbon in molten iron and cooling under great pressure. Finally, the highly crystalline structure of meteoric iron points to the same conclusion. No artificial iron shows that peculiarity. All the evidence points in one direction, and the similarity of origin of stones and irons seems to be almost beyond doubt. Both stones and iron were formed in a cooling globe which in structure resembled the cooling Earth. This theory as to the origin of meteorites is the only one that is supported by positive evidence; all others are purely speculative. The theory is not original with me. It was advocated by Meunier and others and has since been fully discussed by Farrington,[22] who has made use of much the same evidence as I have cited here. He also calls attention to the fact that meteoric stones sometimes show indication of strains and of brecciated structure, similar to corresponding features that are common in the crust of the Earth. Farrington's arguments in support of his thesis seem to be incontestable.

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[20] Op. cit.

[21] System of mineralogy, 6th ed., pp. 28, 29, 1914.

The lines of evidence used by Farrington in his argument have recently been made much stronger by the study of a meteoric stone that fell at Cumberland Falls, Ky., on April 9, 1919. This stone, which has been thoroughly investigated by Merrill,[23] is made up of two distinct types of meteorites. The larger part is white and consists mainly of enstatite with a little diallage. It contains, however, inclusions of a black stone, made up of olivine and enstatite. There are also some scales of graphite, with a very little nickel-iron and troilite. The most noteworthy feature of the stone is that the white portion, instead of being comparatively homogeneous, is a breccia, a mass of sharply angular fragments, which could be formed only by crushing the rock under great pressure or by grinding. The only interpretation that can be given to these facts is that the meteorite is a fragment of a much larger mass, of what may be called subplanetary dimensions—one large enough for the same processes to operate that are recognized in the rocks of the Earth. How and when that planetoid was disrupted we do not know, and speculation upon that subject would be out of place in this paper.[24] Its chemical composition, however, as shown by the analyses of meteorites, must have closely resembled that of the Earth.

To complete the analogy between the Earth and the broken planetoid we should be able to calculate the percentage composition of the latter. This, however, can not be done, for much of the meteoric matter is lost. In the catastrophe that destroyed the planetoid its lighter, outer shell was probably scattered in dust, or in fragments so small that few of them, even if they reach the Earth, could ever be collected and identified. No granitic meteorite has yet been found, and the only distinctly feldspathic meteorites are those of the Juvinas and Stannern types, in which the feldspar is anorthite. Alkali feldspars occur in meteorites in very small and relatively unimportant proportions.

The suggestion that the outermost portion of the planetoid was lost is not altogether imaginative. It is supported by the well-known phenomena that attend the fall of a large meteor. These are a brilliant light and a violent explosion, with a noise which has been compared to thunder or the firing of heavy artillery. The meteor is also followed by a train of sparks as seen by night, or one of "smoke" in daytime. An explanation of these phenomena was put forth by Maskelyne[25] in 1862, about as follows: The meteor, coming from the cold of outer space, enters the atmosphere of the Earth with something like planetary velocity. By atmospheric friction its surface is almost instantly heated to incandescence; this portion of course expands and breaks away from the central mass with explosive violence. In this way the meteor is disrupted, and the fragments that are thrown off are seen in the trail of sparks or smoke which follows the falling mass. This explanation of the phenomena is very simple and seems to be satisfactory. The meteoric stone has just the composition which would result from the process described above. Its lighter surface has been blown away, and only the denser, interior portion of different composition has fallen to the ground.

So far the evidence seems to be conclusive that the meteorites are fragments of a mass of matter which in composition closely resembled the Earth. Of the dimensions of that mass we know nothing, except that it must have been large enough to maintain its integrity at first in a fluid state, and that after it had solidified crustal movements occurred which produced the peculiar structures of meteoric stones. Its disruption took place long ago, how long we can not say; and many, perhaps the greatest number, of its fragments reached the Earth shortly after the catastrophe. Of course we can not assume that there was only one such mass; there may have been more than one, but that question is not germane to the present discussion. The known meteorites show clear indications of a common origin; whether from one or two planetoids we need not ask.

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[22] Farrington, O. C., Jour. Geology, vol. 9, p. 630, 1901.

[23] Merrill, G. P., U. S. Nat. Mus. Proc., vol. 52, p. 97, 1920.

[24] T. C. Chamberlin (Jour. Geology, vol. 9, p. 370, 1901), regards meteorites as fragments of a planetoid which was torn to pieces by near approach to a larger mass.

[25] Maskelyne, N. S., British Assoc. Adv. Sci. Ann. Rept., 1862, pt. 2, p. 188.

From what has been said so far, it is clear that the Earth was once a fluid mass, in which as it cooled the iron separated from the silicates just as it does from the slag in a blast furnace. The solid Earth, then, consists of two components—a nucleus of metallic nickel-iron and an envelope of silicate rocks. This conclusion is by no means new. It has been adopted by many other writers, and especially by Wiechert,[26] whose argument is based on geodetic data. For the composition of the nucleus we have Farrington's average of 318 analyses of meteoric iron, which, however, is subject to correction for its inclusion of other substances. What, now, is the average composition of the lithosphere?

For the composition of the lithosphere we have that of the igneous rocks near its surface and that of the stony meteorites, which are supposed to represent the material closest to the central iron. Between the two, the top and bottom of the lithosphere, there is a wide gap, which can be filled only hypothetically—that is, by making probable or at least plausible assumptions. In the first place we may assume that between the lighter rocks at the surface and the heavier at the bottom there is a fairly regular gradation, from an average andesite above to a peridotite below. In this hypothesis an average basalt may be assumed to fill the gap, without much risk of serious error. For the composition of the basalt we may use the average of 161 analyses as computed by Daly,[27] but reduced here to elementary form. For the mean composition of the lithosphere there are, then, three averages to be combined, as follows: First, the average for the surface rocks; second, that of the basalt; and third, that of the meteoric stones as given by Merrill. In this combination the minor constituents are discarded, as representing small corrections that can be applied when it is desirable to do so. The incompleteness of the meteorite analyses renders the omission necessary. The three sets of figures, given equal weight, appear in the following table, together with their mean, the composition of the lithosphere.

Average composition of the lithosphere.

	Surface rocks.	Basalt.	Meteoric stone.	The lithosphere.
Oxygen	46.72	44.28	42.16	44.38
Silicon	27.76	23.27	21.21	24.08
Aluminum	8.13	8.44	1.70	6.09
Iron	5.12	8.87	15.25	9.75
Magnesium	2.10	3.76	16.12	7.33
Calcium	3.64	6.49	1.48	3.87
Sodium	2.86	2.34	.82	2.01
Potassium	2.60	1.28	.31	1.39
Titanium	.73	.83	....	.52
Manganese	.12	25	.50	.29
Phosphorus	.16	.19	....	.12
Chromium	.06	....	.45	.17
	100.00	100.00	100.00	100.00

It will be noticed that in this average the nickel-iron of the meteoric stones does not appear. It is included in the total amount of metal which is required to bring the density of the Earth up to 5.5.

Here we may venture to use a curious analogy to which Wiechert has called attention.[28] Astronomers are generally agreed that the Moon was originally thrown off from the Earth. If so, its composition should be essentially like that of the lithosphere. Its mean density, 3.34, is that of some meteoritic olivines. That density, however, is too high for the stony portion of the lithosphere and suggests that the Moon contains, like the meteoric stones, some nickel-iron. The average meteoric stone, according to Merrill's calculation, contains nearly 15 per cent of nickel-iron, sulphides, and phosphides. The average density of 78 meteoric stones, as computed by me, is 3.54, a value that fits in well with the figures given above.

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[26] Wiechert, E., Gesell. Wiss. Göttingen Nachr., 1897, p. 221.

[27] Daly, R. A., Am. Acad. Proc., vol. 45, p. 211, 1910.

[28] Wiechert, E., Deutsche Rundschau, vol. 132, p. 376, 1907. English translation in Smithsonian Inst. Ann. Rept., 1908, p. 431.

To the stony matter alone of the lithosphere a probable density of 3.2 may reasonably be assigned.[29] That of the surface crust is about 2.8. For the density of the metallic nucleus the figure 7.8 is commonly assumed, but it may be a trifle too high. No allowance is made for inclusions of lighter material, but a density of 7.7 would probably be a minimum. The mean density of the Earth, as given by different authorities, lies somewhere between 5.5 and 5.6.

With the data now at hand we can compute, at least approximately, the composition of the Earth as a whole and the relative abundance of the elements in the solar system. Wiechert[30] has already shown that the iron nucleus of the Earth and its rocky envelope are roughly equal in volume. If we assign to the Earth and its two components the respective densities of 5.5, 7.8, and 3.2 this relation holds exactly, and no probable changes in these values will greatly modify Wiechert's conclusion. Whatever permissible values we assign to the densities the two volumes will approach equality. The variations will not exceed 3 per cent in either direction—that is, for a little more iron and a little less rock, or vice versa. From the volumes and the densities the relative masses of the two components of the Earth can be determined, and then Farrington's average composition of meteoric iron and that of the lithosphere can be combined together. This combination has already been attempted by Farrington,[31] but with the three densities taken as 5.57, 7.8, and 2.8. Here the figure for the density of the Earth is probably too high, and that of the lithosphere certainly too low. For the composition of the Earth by weight they give 73.6 per cent of free metals and 26.4 per cent of rock. With the densities 5.5, 7.8, and 3.2 the percentages become 70.75 and 29.25, respectively. Considered as representing orders of magnitude, and we can expect nothing more, these two estimates are not very far apart. In the following combination the two percentages are rounded off to 71 and 29. Farrington's combination, however, differs from ours not only in the assumed densities but also in assigning to the composition of the lithosphere that of its 10-mile crust. The two combinations are not comparable.

Average composition of the Earth.

	Nickel-iron (71 per cent.)	Lithosphere (29 per cent.)	The Earth (100 per cent).
Oxygen		44.38	12.77
Silicon		24.08	6.98
Aluminum		6.09	1.86
Iron	90.64	9.75	67.20
Nickel	8.51		6.04
Cobalt	.58		.41
Magnesium		7.33	2.13
Calcium		3.87	1.12
Sodium		2.01	.58
Potassium		1.39	.39
Titanium		.52	.15
Manganese		.29	.08
Phosphorus	.17	.12	.16
Chromium	.01	.17	.07
Sulphur, carbon, copper	.09	(?)	.06
	100.00	100.00	100.00

It needs no argument to show that these figures have no claim to anything like finality and that their value depends upon the assumptions that underlie the calculations. The fundamental assumption, which rests upon pretty definite evidence, is that the original mass of which the meteorites are fragments was similar in composition to the Earth and was formed in the same way.

The second assumption, that the Earth contains a nucleus composed mainly of nickel-iron, surrounded by a stony envelope, is sustained by the facts that the Earth behaves like a huge magnet and that its mean density is about double that of the surface rocks. The application of these facts to the problem in hand involves subordinate assumptions as to the relative densities of the nucleus and the lithosphere. No probable change in the figures assigned to these densities can make any great change in the orders of magnitude as given in the table. The relative order of abundance will be the same, with iron first, oxygen second, silicon third, and so on. As for the scarcer elements, those which do not appear in the table, their total amount can not much exceed 1 per cent, and their inclusion would make only insignificant changes in the percentages assigned to the really abundant substances. After making all reasonable allowances for the scarcer elements, we can say that ten of the more abundant ones, all below 60 in atomic weight, make up at least 99 per cent of all terrestrial matter. They are among the simplest and therefore the most stable elements and were formed in the largest quantities.

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[29] Wiechert (op. cit., 1907), gives a density of 3.4. In his earlier paper he adopts the value 3.2.

[30] Wiechert, E., Gesell. Wiss. Göttingen Nachr., 1897, p. 243.

[31] Farrington, O. C., Field Columbian Mus. Pub. 151, 1911.

This rule, as has been shown already, is revealed by the evidence furnished by the stellar spectra.

Whether all the members of the Solar System are precisely alike in composition is and must remain a matter of conjecture. It is conceivable that the outer planets may be somewhat richer than the Earth in the lighter elements, such as aluminum, magnesium, calcium, and the alkali metals. On the other hand, the Sun may be richer in iron. If that supposition is correct, then the inner planets should approximate an average composition and represent the entire system. This hypothesis, of course, can neither be proved nor disproved. Definite evidence is lacking.

From the analyses of meteoric stones we can obtain some additional suggestions as to the distribution of matter within the Earth. In one of Farrington's papers,[32] which I have already cited, he has tabulated 125 analyses of meteoric stones, classified according to the quantitative system. One analysis falls in the salfemic class, 9 are dofemic, and 94 perfemic. The classes persalane and dosalane are entirely missing, for they belong to the destroyed surface of the wrecked planetoid. Now, these analyses show a distinct gradation in the amounts of nickel-iron which the stones contain. The few feldspathic meteorites, those that were nearest the surface of the parent mass, contain little or no nickel-iron, which increases with some regularity to the end of the perfemic series. The regularity is not sharp and might better be described as a tendency, for the following reasons:

In a single meteorite of large size the nickel-iron is not uniformly distributed, and the analyses were made on small fragments of not more than a few grams in weight. Adjacent fragments might have been either richer or poorer in nickel-iron than those which were analyzed. To analyze a complete stone is never practicable, nor is it feasible to sample a meteorite as one would sample an igneous rock or a carload of ore. These considerations amply account for the irregularities shown by the analyses. In spite of these difficulties the tendency toward a definite arrangement of the meteorites seems to be fairly clear. If they really represent a planetoid that originally resembled a small Earth, the distribution of matter within the Earth as set forth below is highly probable.

At the center of our planet we should have a rather ragged spheroid, with no well-defined margin, consisting mainly of nickel-iron. Near its surface the metal would assume the pallasite type and begin to show inclusions of stony matter, principally olivine. This material would gradually shade into silicate rocks containing large inclusions of free metal, and so on, step by step, until the lighter feldspathic rocks began to appear. These rocks, as the analyses show, contain little or no nickel-iron, and that present occurs in very small, sometimes almost imperceptible grains. The condition thus outlined is exactly what we should expect to result from the slow cooling of a molten globe. The heavier substances should gravitate to the center, followed in order of density by the lighter substances. The evidence at our disposal seems to warrant the conclusions drawn from it. We are dealing, however, with probabilities, not with proofs.

From the evidence presented in the preceding pages some additional conclusions may be drawn. If the Earth consists of a solid nucleus of nickel-iron, surrounded by an envelope of silicate rocks in equal proportions by volume, what is the diameter of the one and the thickness of the other? For the sake of simplicity we may assume ideal conditions, as follows: All the iron is supposed to be concentrated in the form of a perfectly smooth sphere, in uniform contact with its envelope. The volume of the Earth, as generally accepted, is 259,886,000,000 cubic miles. This corresponds to a nuclear diameter of 6,284 miles and a radius of 3,142 miles. Subtracting this figure from the mean radius of the Earth, 3,959 miles, we get 817 miles as the average thickness of the ideal lithosphere. This, however, is only a first approximation to reality, and at least one correction to it is possible.

In calculating the average composition of the lithosphere one-third of it was assumed to be equivalent to an average meteoric stone, but with one qualification. The disseminated nickel-iron, sulphides, and phosphides were withdrawn from the stone and added to the nucleus, making it too large and the true lithosphere too small. The equality of volume as given between nucleus and envelope is really that between the metallic (or rather meteoric) iron and the silicate rocks.

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[32] Farrington, O. C., Field Columbian Mus. Pub. 151, 1911.

The metallic inclusions in the average meteoric stone amount to a little under 15 per cent by weight, and even less by volume. An addition of 5 per cent to the volume of the lithosphere, and a corresponding reduction to the nucleus of the Earth, only lowers the diameter of the nucleus to 6,192 miles and raises the thickness of the lithosphere to 863 miles. This is probably a maximum correction, but any attempt at a greater refinement of the figures would be useless. Absolute accuracy is unattainable, for there is no sharp dividing line between the two components of the Earth. Furthermore, all the data which have been used in the calculations, even those relative to the volume of the Earth and its density, are subject to corrections of undetermined magnitude and direction. There is, nevertheless, a strong probability that the diameter of the nucleus is of the order of 6,200 miles and that the thickness of its envelope is less than 900 miles. Similar figures have been obtained by Wiechert,[33] who assigns to the nucleus a diameter of 10,000 kilometers, or 6,214 miles, to which a thickness of its envelope of 855 miles corresponds. Wiechert's results and mine were reached by entirely different methods, and their close agreement is therefore very satisfactory. Gutenberg,[34] however, from a study of earthquake waves, gives the nucleus of the Earth a radius of only 3,500 kilometers, or 2,175 miles. The corresponding thickness of the lithosphere is 1,784 miles, or double the value found in this investigation. It is for some geodesist to explain this discrepancy.

Up to this point the vexed questions of pressures and temperatures within the Earth have not been considered. On the one hand it has been commonly assumed that because of increasing pressure the densities from the surface to the center of the Earth must have steadily increased, and a similar assumption has been made with regard to temperatures. But here we have two opposing forces, one tending to increase, the other to diminish volumes. Whether these forces balance or not is a question which needs more consideration than I can give it. In its investigation many factors, hitherto generally neglected, have to be taken into account. The Earth is not a homogeneous body. It is made up of many different substances, which are unlike in composition, in density, in fusibility, in specific heat, in conductivity, and in compressibility. Furthermore, we must determine whether compressibility is a limited property of matter or whether it can go on indefinitely. It is also necessary to consider the comparatively abrupt change from the envelope of silicate rocks to a nucleus of metallic iron, which seems to be sustained by strong evidence. The rocky shell of the Earth is more compressible than its metallic interior. Anything like a regular increase of density within the Earth because of an assumed increase of pressure is highly improbable. Unlimited compressibility would end in zero volume, which is absurd. There must be a limit somewhere, where pressure and the resistance to pressure exactly balance, and that limit may have been reached in the metallic nucleus of the Earth, an inference which is suggested by the rigidity of our planet. If it has not been reached then the volume of the Earth must be slowly shrinking, but of that there are no clear indications.

The assumption that temperatures within the Earth increase regularly with the depth is based upon a very short range of observations. In deep wells and other borings the temperature increases, but not to the same extent in all localities, the average amount being about 1° F. in 60 feet. The actual measurements are limited to depths of only a little more than a mile, and by extrapolation the conclusion has been reached that at the center of the Earth the temperature must be high enough to surpass the critical temperatures of all known substances. The temperature of the Sun, which is now well fixed as something like 6,000° C., would thus be exceeded many times over. Extrapolation sometimes leads to very surprising conclusions.

Let us now consider the heat of the Earth under two distinct headings—namely, residual or original heat and new heat such as is constantly being generated. By residual heat is meant that which was retained by the cooling Earth within its interior, mainly in its nucleus and to a less degree in the lithosphere. At and near the surface of the Earth the new heat becomes evident as the result of chemical activity, friction, and several other causes. The heat derived from radium, as shown by the radioactivity of the rocks, has in recent years received much consideration, but its importance may have been exaggerated. It is, however, not negligible. That due to the impact of meteorites is relatively insignificant.

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[33] Gesell. Wiss. Gottingen Nachr., 1897, p. 243.

[34] Gutenberg, B., idem, 1914, p. 176.

That chemical changes are constantly taking place in the crust of the Earth is a matter of common observation, and each one has definite thermal significance. Some reactions are exothermic and others are endothermic, but whether these gains or losses of heat balance or one or the other predominates is difficult and perhaps impossible to determine. Rocks are decomposed by the joint action of air and water, and heat is both gained and lost in the rather complex processes. The intensity of the reactions is greatest, of course, in humid areas and least in desert regions; it can not be the same for all localities. To discuss this question at length would hardly be justifiable in a paper of this kind: it is enough to show that the question deserves consideration. Even the heat emitted by volcanoes is in part, if only a small part, of chemical origin. The heat of some coal mines and of mines in which sulphide ores are worked is due to oxidation. Examples like these might be multiplied indefinitely. In many of the changes solar radiations also take part, and energy that may be released later is stored up within the Earth.

The crust of the Earth is constantly in motion, and every movement is accompanied by friction. The slightest tremor generates its share of heat, and its aggregate amount must be enormous. Mountains are raised to great elevations; rocky strata are folded, bent, broken, or distorted; there are landslides and all the varieties of erosion; and every one of these movements, great or small, is a source of what I have called new heat. Even volcanic heat is partly and perhaps largely due to friction. Volcanoes, as a rule, are situated along lines of weakness in the crust of the Earth, where earthquakes (and consequently friction) are most common.

All or nearly all of this new heat is generated at or near the surface of the Earth. Below the level of isostatic compensation, the depth at which surficial excesses and defects of density are balanced, there can hardly be much chemical activity and very little friction. An earthquake wave may penetrate to much greater depths, probably to the margin of the nucleus, but its thermal significance diminishes as it recedes from its focus, and below the isostatic level, which is put at about 60 miles, it can not be very great. At greater depths the temperature, whatever it may be, is due to residual heat and is not higher than the average melting point of igneous rocks.

The conditions in the nucleus of the Earth are very different from those in the lithosphere. Here we have a metallic mass more than 6,000 miles in diameter, which is a good conductor of heat. It is practically insulated by a shell of poorly conducting rock at least 800 miles thick. Under such conditions, because of its conductivity, the temperature of the nucleus should be uniform or nearly so throughout and below the melting point of iron, or 1,600° C. This conclusion implies that the nucleus has attained a state of stable equilibrium, which is also indicated by the established fact that the Earth as a whole is rigid. Only near the surface is this rigidity disturbed.

NOTE.—Some valuable determinations of the compressibility of rocks and minerals have recently been published by L. H. Adams and E. D. Williamson (Franklin Inst. Jour., April, 1923). Their data, as applied to the present discussion, show that the granitic rocks are the most compressible, and the denser rocks much less so. Granite is about three times as compressible as iron. From the surface of the earth to its nucleus, therefore, the compressibility diminishes, and the resistance to pressure must steadily increase.

THE DISINTEGRATION OF THE ELEMENTS.

Our direct, experimental knowledge of atomic disintegration began with the discovery by Ramsay and Soddy in 1903 of the emission of helium from radium. This discovery, however, was the outgrowth of two earlier discoveries—that of radioactivity by Becquerel in 1896 and of polonium and radium by the Curies two years later. From these beginnings a new field of chemical and physical research has developed, which is already rich in fundamental discoveries and is represented by a voluminous literature.

The study of radioactivity, however, covers only one phase of the main problem of elemental decay. As soon as it was clearly recognized that the most complex elements were spontaneously decomposing, investigators began to attack the problem along other lines of research, some of them experimental and others mathematical. The atoms that had been regarded as simple were seen to be complex, and it was sought to determine their structure. Attempts were and are still being made to decompose the chemical elements by artificial means, and some significant evidence of disintegration has been furnished by astronomy.

The study of radioactivity is primarily, although not entirely, a study of the radiations which the most complex elements emit. These radiations are of three kinds, known as alpha, beta, and gamma rays, which differ in velocity and in the extent to which they can penetrate an obstacle in their paths, such as a sheet of aluminum foil. The different products of radioactivity—that is, of atomic disintegration—are identified chiefly by the character of their radiations. The alpha rays are composed of helium atoms, the beta rays are "atoms" of negative electricity, and the gamma ray is regarded as possibly an electrically neutral doublet of two electrons of opposite sign. Through the study of these radiations more than thirty new substances have been discovered, which have received names and to which have been given atomic weights (except in the actinium series) and atomic numbers. In the following table, which is abridged from that recently published by the International Commission on the Chemical Elements, the present state of our knowledge of the radioactive elements is well shown. Some details, not needed in the present discussion, have been omitted from the complete table. The letter T at the head of the first column refers to the "period" of each substance—that is, the time in which the quantity of an "element" is diminished to one-half, the "half-life period," as it is commonly called. The column headed "radiation" gives the characteristic rays which the substances emit.

This table evidently has no claim to finality. It is a valuable summary and classification of experimental data, but it also contains implications which sooner or later must be revised. The basic facts are as follows: Uranium and thorium are slowly decaying, and in doing so they generate series of products which are also unstable and which seem to end in the formation of lead. A few of these products are long-lived, with periods measured by years; others change with almost incredible swiftness, and for some of them the periods consist only of minutes, or even of small fractions of a second. The disintegration of uranium and its products follows two distinct lines—one through ionium and radium, the other forming the actinium series. The thorium series, so far as we know, is single.

Each of the three series given in the table divides at about its middle into two parts, with the line of demarcation marked by the appearance of the gaseous emanations of radium, actinium, and thorium X. For these emanations the names "radon" (formerly niton), "actinon," and "thoron" are proposed. These emanations are short-lived and give rise as they decay to what are called "active deposits," which are nonvolatile and can be collected and concentrated upon negatively charged metallic points or surfaces. These deposits in turn decay, and so on to the end of the series.

Now, without doubting the accuracy of the experimental data upon which the foregoing table is based, we may examine the inferences that are drawn from them. Here we must again point out the difference between normal and abnormal or defective elements. The normal elements are those which were developed in the ordinary course of evolution; the abnormal elements are those which were produced by decay. The difference between the two classes is very definite. The normal atoms are believed to be veritable storehouses of potential energy. In the series of radioactive elements that energy is becoming partly kinetic. The distinction is perfectly clear. Some of the products of radioactivity are too ephemeral to be called elements at all. They represent matter in a state of transition from one form to another, and the atomic weights assigned to them are purely hypothetical. As for uranium and thorium, they are partly decayed and are still decaying, but they must have been originally developed as normal elements under conditions of pressure or temperature of which we know nothing. To quote an apt remark of Eddington,[35] in his lecture upon the borderland between astronomy and geology: "In radioactivity we see a mechanism running down which must at some time have been wound up." This fits the cases of uranium

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[35] Eddington, A. S., Nature, Jan. 6, 1923.

The radioactive elements.

The uranium-radium series.

T.	Name.	Symbol.	Atomic weight.	Atomic number.	Isotope.	Radiation.
4.67×10^9 years	*Uranium I*	UI	238	92	U	α
24.6 days	*Uranium X_1*	UX_1	234	90	Th	β
1.15 minutes	*Uranium X_2*	UX_2	234	91	Pa	β (γ)
2×10^6 years	*Uranium II*	UII	234	92	U	α
6.9×10^4 years	*Ionium*	Io	230	90	Th	α
1690 years	*Radium*	Ra	226	88	Ra	α (β+γ)
3.85 days	*Radon*	Rn	222	86	Rn	α
3.0 minutes	*Radium A*	RaA	218	84	Po	α
26.8 minutes	*Radium B*	RaB	214	82	Pb	β (γ)
19.5 minutes	*Radium C*	RaC	214	83	Bi	99.97% β and γ
10^{-6} second	*Radium C′*	RaC′	214	84	Po	α
16.5 years	*Radium D*	RaD	210	82	Pb	(β and γ)
5.0 days	*Radium E*	RaE	210	83	Bi	β
136 days	*Radium F* (Polonium)	RaF (Po)	210	84	Po	α (γ)
....	*Radium Ω′* (Lead)	Ra Ω′ Pb^{206}	206	82	Pb	....
....	*Radium C*	RaC	214	83	Bi	0.03%α
1.4 minutes	*Radium C″*	RaC″	210	81	Tl	β
....	*Radium Ω″*	RaΩ″	210	82	Pb	....

The actinium series.

....	*Uranium ?*	....	?	92	U	α
1.04 days	*Uranium Y*	UY	?	90	Th	β
1.2×10^4 years	*Protoactinium*	Pa	?	91	Pa	α
20 years	*Actinium*	Ac	?	89	Ac	—
19.5 days	*Radioactinium*	RdAc	?	90	Th	α (β)
11.4 days	*Actinium X*	AcX	?	88	Ra	α
3.9 seconds	*Actinon*	An	?	86	Rn	α
2.01×10^{-3} second	*Actinium A*	AcA	?	84	Po	α
36.1 minutes	*Actinium B*	AcB	?	82	Pb	(β and γ)
2.15 minutes	*Actinium C*	AcC	?	83	Bi	α
4.71 minutes	*Actinium C″*	AcC″	?	81	Tl	β and γ
....	*Actinium Ω″* (hypothetical)	Ac Ω″	?	82	Pb	....

The thorium series.

1.31×10^{10} years	*Thorium*	Th	232	90	Th	α
6.7 years	*Mesothorium 1*	MsTh1	228	88	Ra	—
6.2 hours	*Mesothorium 2*	MsTh2	228	89	Ac	β and γ
2.02 years	*Radiothorium*	RdTh	228	90	Th	α (β)
3.64 days	*Thorium X*	ThX	224	88	Ra	α
54 seconds	*Thoron*	Tn	220	86	Rn	α
0.14 second	*Thorium A*	ThA	216	84	Po	α
10.6 hours	*Thorium B*	ThB	212	82	Pb	β and γ
60 minutes	*Thorium C*	ThC	212	83	Bi	65% β
10^{-11} second	*Thorium C′*	ThC′	212	84	Po	α
....	*Thorium Ω′* (Lead)	Th Ω′ Pb^{208}	208	82	Pb	....
....	*Thorium C*	ThC	212	83	Bi	35% α
3.1 minutes	*Thorium C″*	ThC″	208	81	Tl	β and γ
....	*Thorium Ω″* (Lead)	Th Ω″ Pb^{208}	208	82	Pb	....
....	*Potassium*	K	39. 1	19	K	β
....	*Rubidium*	Rb	85. 5	37	Rb	β

and thorium exactly. When the conditions that permitted the evolution of uranium ended, then disintegration began.

The atomic weights of normal uranium and thorium are unknown.

The values assigned to them really represent mixtures of the normal elements with some of their decomposition products, of which we know only those that are revealed by their radiations. That there may be residues left behind which are as yet undiscovered seems to be unquestionable. The actual determinations of atomic weight were made with masses of material containing millions of atoms, some of them intact and others represented by unexpelled products of disintegration. If all the atoms were broken down at once, there would be neither uranium nor thorium left. Furthermore, the atomic weight assigned to thorium is affected by another complication. It is doubtful whether any thorium compounds are known which are quite free from its isotope, ionium. The atomic weight of ionium has been shown by Honigschmid to be at least as low as 231.5, and probably lower. That of purified thorium must certainly be higher than the accepted 232.2, but the exact value is undetermined. The presence of ionium gives it too low a value.

The atomic weights and numbers assigned to the products of radioactive decay are, with a few exceptions, hypothetical. The atomic weight of radium as actually determined is 225.95, and it falls into place in the periodic system. For its emanation, radon, the value is near 222, but the determination is not as exact as is desirable. Radium, moreover, and also radon are still decaying, and the values given to them are therefore subject to the same uncertainties as those which affect the atomic weights assigned to uranium and thorium. If corresponding normal elements exist, their atomic weights should be somewhat higher. The so-called isotopes of lead will be considered later.

From what has been said in the preceding paragraphs it is evident that the atomic weights and numbers assigned to the radioactive "elements" are in need of careful revision. The atomic weights start from two that are certainly in error and are developed on the assumption that each step downward is due entirely due to the loss of alpha particles. But does that loss represent all the change which has taken place? And how large a proportion of the atoms in a given mass of uranium or thorium has been decomposed? Furthermore, is Moseley's law of atomic numbers applicable to products of decay—for example, to radium C′? That product of radioactivity has a period of only 10^{-6} second; it comes into existence, pays a flying call on atomic number 84, and then vanishes. To call such a substance an element verges on absurdity. Moseley's law may be valid for the normal elements, but it has not yet been tested throughout the scale of atomic weights. The evidence in its favor is incomplete. In the actinium series no atomic weights are assumed, for the reason that the exact ancestry of actinium is still uncertain. None of these doubts, however, attaches to the atomic weights of potassium and rubidium, two metals which are feebly radioactive but are independent of the uranium and thorium series.

In the table of the radioactive elements six members are reported as isotopes of lead. That is, although the atomic weights assigned to them range from 206 to 214, they are given the same atomic number with lead, No. 82, and appear in the same place in the periodic classification. These isotopes are radium B, radium D, actinium B, actinium D, uranium lead, and thorium lead. Three of them are short-lived and need not be considered further here. Radium D, however, sometimes called "radio-lead," is part of the active deposit of radon: and it has been collected in sufficient quantity for qualitative tests and gives some reactions that are like those of normal or ordinary lead. Its period is 16.5 years, and its hypothetical atomic weight is 210.

The two isotopes that end the radioactive series, uranium lead and thorium lead, are on a different footing from the others. They are obtained from minerals containing them in sufficient quantities for good determinations of atomic weight. These determinations give different values for the lead from different sources, showing that mixtures of normal lead with its isotopes are of common occurrence in radioactive minerals. In the most perfect and brilliant crystals of uraninite, which are found in granitic pegmatites, normal lead seems to be absent, and the isotopic lead has an atomic weight very close to 206, the lowest value yet found. For thorium lead, derived from ores of thorium, the lowest value is 208. Are these the real ends of the radioactive series, or does disintegration proceed still further? So far, this question is not completely answered.

The existence of these isotopes has led to a belief, or rather a suspicion, that ordinary lead is a mixture and not a single definite substance. How far is this suspicion verified? Is the atomic weight of ordinary lead constant or variable? To answer these questions Baxter and Grover made elaborate series of analyses of lead bromide and chloride from very different sources. Lead was obtained from galena, cerusite, vanadinite, and wulfenite, and the minerals came from widely separated localities—namely, Idaho, Arizona, Washington, Missouri, Germany, and Australia. Four different minerals and seven localities furnished the material for the determinations, and commercial lead nitrate was also included in the investigation. Four series of determinations were made, giving average values for the atomic weight of lead ranging from 207.18 to 207.23, an extreme difference of 1 part in 4,144, which is quite within the allowable limits of experimental uncertainty. The atomic weight of normal lead is a definite quantity and not a statistical average of the different values found for its isotopes. To maintain such a uniform average the isotopes should always be mixed in exactly the same proportions, and that is extremely improbable.

One very uncertain assumption has been made as to the nature of isotopes. Those of lead, for instance, are said to be chemically identical and not separable by chemical methods. That simply means that no such separation has yet been effected; but there is no proof that it may not be effected in the future. The prediction of impossibilities is not always verified. Many failures are on record.

That the products of radioactivity are products of decomposition is proved, but their definiteness is not so certain. All or nearly all of them are unstable and undergoing change, some rapidly and others with extreme slowness. Their isotopy, moreover, is largely hypothetical, for how can two products be called isotopic when both are undergoing alteration and at different rates? Only for uranium lead and thorium lead can isotopy be regarded as established, and even for these the claim must be held with reservations. The isotopes differ from normal lead in some physical properties, but that they are its equal as regards stability is still uncertain. The stable product of evolution and the products of decomposition are not quite the same. Their similarity may be illusive. This possibility should not be ignored.

Reference has already been made to Aston's work on "mass spectra"—work which is of great value, regardless of any interpretation that may be put upon it. Are his isotopes substances of the same order as those that appear in radioactivity?

The "mass spectra" described by Aston[38] represent an artificial disintegration of elements, and his process is roughly as follows: An element or one of its compounds is bombarded by powerful positive rays in a magnetic field. The rays, differently deflected, finally impinge upon a carefully calibrated photographic plate, upon which they give lines that are interpreted as belonging to isotopes. From the position of these lines the atomic weights of the isotopes are determined within a supposed accuracy of 1 part in 1,000, or one-tenth of 1 per cent, a rather large uncertainty.

It is not necessary for present purposes to go into the details of Aston's work. They are fully given in his book on isotopes. Suffice it to say that his apparatus, his "mass spectograph," is very complicated, and his technique is exceedingly refined. The essential fact is that the elements undergo certain changes when subjected to the action of positive rays. Other methods for attaining results similar to Aston's have been developed by Sir J. J. Thomson and by A. J. Dempster, but they also are applications of what is called positive-ray analysis. The products of these analyses, regarded as isotopic, are given in the following table, which is abridged from the table published by the International Commission on the Chemical Elements in 1923. The figure relating to glucinum is due to G. P. Thomson; those of magnesium, calcium, and zinc, to Dempster; all the others are Aston's. A number inclosed in parentheses is doubtful.

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[38] Aston, F. W., Isotopes, London, 1922.

Isotopes.

Element.	Atomic number.	Atomic weight.	Minimum number of isotopes.	Masses of isotopes.
H	1	1.008	1	1.008
He	2	4.00	1	4
Li	3	6.94	2	7; 6
Gl	4	9.02	1	9
B	5	10.9	2	11; 10
C	6	12.005	1	12
N	7	14.008	1	14
O	8	16.000	1	16
F	9	19.0	1	19
Ne	10	20.2	2	20; 22
Na	11	23.00	1	23
Mg	12	24.32	3	24; 25; 26
Al	13	27.0	1	27
Si	14	28.1	2	28; 29; (30)
P	15	31.04	1	31
S	16	32.06	1	32
Cl	17	35.46	2	35; 37
A	18	39.9	2	40; 36
K	19	39.10	2	39; 41
Ca	20	40.07	(2)	40; (44)
Fe	26	55.84	(1)	56; (54) ?
Ni	28	58.68	2	58; 60
Zn	30	65.37	4	64; 66; 68; 70
As	33	74.96	1	75
Se	34	79.2	6	80; 78; 76; 82; 77; 74
Br	35	79.92	2	79; 81
Kr	36	82.92	6	84; 86; 82; 83; 80; 78
Rb	37	85.45	2	85; 87
Sn	50	118.7	7 (8)	120; 118; 116; 124 119; 117; 122; (121)
I	53	126.92	1	127
Xe	54	130.2	7 (9)	129; 132; 131; 134; 136; 128; 130; (126); (124)
Cs	55	132.81	1	133
Hg	80	200.6	(6)	(197-200); 202; 204

What do the figures in the last two columns of the foregoing table really mean? Do they represent isotopes in the accepted meaning of the term, which are merely separated by the bombardment? Or are they a record of an elemental disintegration? These alternative interpretations are both tenable, and each one can be sustained by cogent arguments. The second question is answered by Aston in the affirmative; and his views have been generally acepted or at least favored. On the other hand, the isotopes of the radio active series are definitely products of decomposition, and those of the mass spectra may be of the same order.

The last column of the table is extremely suggestive. The simplest elements, those of low atomic weight, show little or no isotopy. Twelve of them are simple substances and may be called pure or normal élements. Nine of them, up to and including nickel, are doubled, and two are represented as triplets. With zinc a greater degree of complexity appears, which, with some exceptions, tends to increase as the atomic weights become larger. This increase, however, represents only a distinct tendency, not a definite law. How far th's rule may hold remains to be determined; and it is extremely desirable that the mass spectra of the elements above mercury in the scale of atomic weights should be examined—namely, those of thallium, lead, bismuth, thorium, and uranium. Such an examination would render a direct comparison with the radioactive series possible. Would the mass spectrum of lead, for example, show the same isotopes as those which have been revealed by radioactivity? That of uranium, also, should be very instructive. The most complex elements are the most easily decomposable and should show the greatest number and variety of fractions.

So far the evidence favors the hypothesis of decomposition; but there is also evidence to support the isotopic theory. By diffusion or by distillation three elements—namely, chlorine, zinc, and mercury—have been separated into fractions that differed in density and in atomic weight. Harkins and his colleagues,[37] by fractional diffusion of gaseous hydrochloric acid, have partially separated it into two portions, one heavier and the other lighter than the ordinary compound. The heavier portion gave an atomic weight for chlorine of 35.4918, which is 0.1 per cent higher than the accepted value, 35.46. The latter value has been determined with the greatest accuracy and is probably correct within 1 part in 10,000. Results similar to those of Harkins and Hayes, but by a different method, have been obtained by Brönsted and Hevesy,[38] who separated hydrochloric acid into two fractions corresponding to a difference of 0.024 in the atomic weight of chlorine. The chlorine atom, then, seems to be a doublet; but the remarkable uniformity of its chemically determined atomic weight is difficult to explain. A mere mixture of two isotopes could hardly be so definite unless all the compounds of chlorine that were used in the determination of its atomic weight had a common origin. That possibility is still under investigation. Is the chlorine of volcanic emanations, of meteoric iron, of oceanic salts, and of igneous rocks always the same thing, and of one definite atomic weight?

By fractional distillation mercury has been separated into two portions, one heavier than the other, as in the case of chlorine. Harkins and Madorsky[39] evaporated mercury in a vacuum and obtained two fractions that gave differences from the accepted atomic weight of the metal of +0.052 and −0.044. Brönsted and Hevesy,[40] by a similar process, obtained results of the same order. The same chemists, however, in a later investigation,[41] determined the density of ordinary mercury from ten widely separated sources and found differences of only 2 to 6 units in 10 millions. These differences in density correspond to differences in atomic weight of 0.0004 to 0.0012.

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[37] See especially Harkins, W. D., and Hayes, A., Am. Chem. Soc., Jour., vol. 43, p. 1403, 1921.

[38] Brönsted, J. N., and Hevesy, G., Nature, vol. 107, p. 619, 1921.

By very thorough determinations of atomic weight Hönigschmid and Birckenbach[42] have completed the evidence as to the composite nature of mercury. Brönsted and Hevesy supplied them with samples of their heavy and light fractions, with which the determinations were made—for the heavier fraction, Hg = 200.628 to 200.638; for the lighter fraction, Hg = 200.562 to 200.568. These differences are conclusive. For ordinary mercury the same chemists, aided by M. Steinheil,[43] found Hg = 200.61, the accepted value.

Ordinary or normal mercury, if we may call it so, is therefore uniform in character far within the limits of experimental uncertainty. The same is true of lead, as we have already seen; and the work of Baxter and his colaborers have shown it to be true of iron and nickel. The atomic weights of terrestrial iron and nickel are identical with those of the two meteoritic metals. In order to account for this uniformity we must assume in each case that the component isotopes must always have been mixed in constant and definite proportions.

For the possible complexity of zinc there is only the work of Egerton,[44] who in a preliminary note reports finding small differences in the density of the metal after distillation in a high vacuum. Two fractions gave densities of 0.9971 and 1.00076, when that of the initial substance was taken as unity. These results are regarded as promising.

So far a partial separation of chlorine and mercury into distinct fractions has been accomplished, although the differences between the fractions are very small. A complete separation is yet to be effected, so that each fraction can be weighed and examined by itself. If the mass spectra really represent isotopes there should be twelve possible isotopes of mercuric chloride, ranging in molecular weight from 232 to 241, a difference of 9 units in atomic mass. The fractional crystallization of mercuric chloride, then, or else precipitation of the mercury either by electrolysis or with some suitable reagent, might yield definite results. Other lines of attack upon the problem of separation have been suggested, and they are summarized by Aston in his book. Greater detail is not needed here.

Evidence of an entirely different character as to disintegration of elements has recently been obtained by Rutherford.[45] His procedure, briefly, is as follows: A stream of powerful alpha rays, emitted from a very thin film of radium C, is passed through a current of hydrogen. A number of high-speed hydrogen atoms are liberated, which strike upon a screen of zinc sulphide and produce scintillations that can be observed through a microscope and counted. Between the zinc sulphide and the radioactive source thin screens of mica are inserted, which can be varied in thickness, so as to measure the relative penetrating power of the alpha particles and of the hydrogen atoms. The range of the hydrogen atoms is much greater than that of the alpha rays and so gives a datum for their identification. Their appearance, as found by the scintillations on the zinc sulphide, identifies them as hydrogen.

Suppose, now, that some other gas replaces hydrogen. With nitrogen the same long-range particles appear, this giving evidence that the lighter element is a constituent of the nuclei of the heavier atoms and has been separated from them. With oxygen or carbon dioxide no such change is observed, a very significant difference. The molecular weights of these gases are whole multiples of that of helium, from which carbon and oxygen are supposed to have been built up.

By this general method, with modifications in the case of solid substances, Rutherford has tested all the elements up to atomic weight 40, with the exception of helium, neon, and argon. Several other elements, higher in the

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[39] Harkins, W. D., and Madorsky, S. L., Am. Chem. Soc. Jour., vol. 45, p. 591, 1922.

[40] Brönsted, J. N., and Hevesy, G., Nature, vol. 106, p. 145, 1921.

[41] Zeitschr. anorg. allgem. Chemie, vol. 124, p. 22, 1922.

[42] Honigschmid, O., and Birckenbach, L., Deutsch. chem. Gesell. Ber., vol. 56, p. 1219, 1923.

[43] Idem, p. 1212.

[44] Egerton, A. C., Nature, vol. 110, p. 773, 1922.

[45] Rutherford, Sir Ernest, Nature, vol. 109, pp. 584–586, 614–617, 1922.

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AN EARLY EOCENE FLORULE FROM CENTRAL TEXAS

BY

EDWARD WILBER BERRY

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Shorter contributions to general geology, 1923-24
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AN EARLY EOCENE FLORULE FROM CENTRAL TEXAS.

By Edward Wilber Berry.

In 1916 I described [1] a florule collected by Alexander Deussen and L. W. Stephenson at the town of Earle, in Bexar County, Tex. This florule was tentatively considered of Midway age by these geologists, and examination of the fossil plants tended to confirm this assignment, particularly because of their lack of harmony with the extensive Wilcox flora described in the volume cited above and because of their resemblance to the described floras from the Raton and Denver formations of Colorado and New Mexico.

Subsequently, without any very definite evidence, the rocks in the area around Earle came to be regarded as of Wilcox age and were so mapped by Sellards.[2] I visited the locality in 1921 in company with A. C. Trowbridge and L. W. Stephenson but found no additional plant species.

Recently I received from O. M. Ball, of the Agricultural and Mechanical College of Texas, a small collection of fossil plants obtained near Sayersville, which is about 8 miles north of Bastrop, in Bastrop County. This collection was found to represent the same flora as that found at Earle and had been preserved in a lithologically identical sandstone. This locality is about 100 miles northeast of Earle and is in about the same relative position in the belt in Bastrop County mapped as Wilcox on Deussen's new map [3] as the locality at Earle in the Wilcox belt in Bexar County shown on the same map.

The Bastrop County locality is along the railroad about 100 yards north of the station at Sayersville. The sandstone in which the fossil leaves were found is overlain by about 10 feet of reddish clay and consists of mostly coarse, well-rounded grains in a highly calcareous cement. It is very similar in appearance to the concretionary masses often found in the Midway of Texas and is exactly like that containing the leaves at Earle, in Bexar County.

The florule from Earle contains the following species:

Pourouma texana Berry.
Ficus denveriana Cockerell.
Ficus occidentalis (Lesquereux) Lesquereux.
Ficus sp.
Platanus aceroides latifolia Knowlton.
Cinnamomum affine Lesquereux.
Laurus wardiana Knowlton.
Asimina eocenica Lesquereux.
Dolichites deusseni Berry.
Terminalia hilgardiana (Lesquereux) Berry.

Of these 10 species but 3—*Ficus denveriana*, *Ficus* sp., and *Terminalia hilgardiana*—had been recorded from the very extensive Wilcox flora, and in part because of this fact, coupled with the total absence of the genera *Pourouma*, *Platanus*, and *Dolichites* in the Wilcox, I was led to consider the Earle outcrop more probably Midway than Wilcox.

The recent collection from Bastrop County contains the following species:

Pourouma texana Berry.
Laurus wardiana Knowlton.
Asimina eocenica Lesquereux.
Terminalia hilgardiana (Lesquereux) Berry.
Asplenium primero Knowlton.
Viburnum sp.
Mespilodaphne precoushatta Berry, n. sp.
Rhamnites marginatus apiculatus?
Ficus post-trinervis Knowlton.
Rhamnus sp.
Terminalia lesleyana (Lesquereux) Berry.
Sapindus? sp.

Four of these species—*Pourouma texana*, *Laurus wardiana*, *Asimina eocenica*, and *Terminalia hilgardiana*—are common to the two localities and are the most abundant forms at both. The combined list from these two localities amounts to 18 species, of which four are doubtfully determined because of their fragmentary nature or lack of specific character due to the coarseness of the matrix.

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[1] Berry, E. W., The lower Eocene floras of southeastern North America: U. S. Geol. Survey Prof. Paper 91, pp. 8–20, 1916.

[2] Sellards, E. H., The geology and mineral resources of Bexar County: Texas Univ. Bull. 1932, 1920.

[3] Deussen, Alexander, Geology of the Coastal Plain of Texas west of Brazos River: U. S. Geol. Survey Prof. Paper 126, pl. 8 (in press).

The aspect of this assemblage as a whole is in rather marked contrast to that of the known Wilcox flora, which consists, according to the latest revision,[4] of 353 species and constitutes as complete and representative a flora as has been found at any geologic horizon. Of this large number of plants in the Wilcox only six, and one of these doubtfully, have been recognized at Earle or Sayersville, and this is exactly one-third of the forms represented at the two localities. Twelve species, or two-thirds of the whole, are different from anything known in the large Wilcox flora. Three of these are peculiar to the two localities in Bexar and Bastrop counties; nine have been found elsewhere. Of these nine species, one occurs in the Denver, Fort Union, and Hanna formations and doubtfully in the Mesaverde formation; six occur in the Raton formation; three occur in the true Laramie, and one of these is doubtfully recorded from the Dawson arkose. Of the forms common to the known Wilcox, three are certainly and one additional is doubtfully recorded from the Laramie, and one of these is found in the Lance.

The Wilcox flora falls naturally into lower, middle, and upper assemblages, and these have demonstrated that the Wilcox sedimentation was transgressive both northward up the Mississippi embayment and westward west of Mississippi River. No lower Wilcox plants have been recognized at any outcrops west of the Mississippi unless the plants from Earle and Sayersville are lower Wilcox.

Of the six Wilcox plants found at Earle and Sayersville one, *Ficus denveriana*, is known only from the upper Wilcox, but as this species is commoner in and characteristic of the Denver and Raton formations of the West, which I regard as older than the Wilcox, it can not be considered as indicative of age within the Wilcox. Another, *Ficus* sp., is found in the middle Wilcox. The other four—*Ficus occidentalis*, *Rhamnus marginatus apiculatus*, *Terminalia hilgardiana*, and *Terminalia lesleyana*—range from the bottom to the top of the Wilcox, and the occurrence of all of these, except the *Rhamnus* in the Raton formation of Colorado and New Mexico, which is probably older than the Wilcox, stamps these forms as abundant, long ranging, and without precise stratigraphic significance.

The Wilcox group in Alabama, where it contains marine faunas, is divided into four formations—from oldest to youngest the Nanafalia, Tuscahoma, Bashi, and Hatchetigbee. To the northwest, in Mississippi, where the sediments pass into those representing Eocene barrier beaches and lagoonal and estuarine clays, marine fossils are almost entirely absent, and the Wilcox group is divided, in ascending order, into the Ackerman, Holly Springs, and Grenada formations, each characterized by distinctive floral assemblages. In Tennessee the Wilcox deposits have not yet been differentiated into formations and are included in the Lagrange formation, although the floras of the Holly Springs and Grenada formations of Mississippi are represented in Tennessee.

There is some faunal as well as other evidence for correlating the Grenada formation of Mississippi with the Hachetigbee formation of Alabama. The Holly Springs sand of Mississippi is thought to represent the Bashi formation of Alabama, with its faunal and other evidence of the shoaling of the water; and the Ackerman formation of Mississippi is thought to represent the Tuscahoma formation of Alabama and also more or less of the upper part of the Nanafalia formation. The relations sketched above are shown graphically in a paper published in 1915,[5] and subsequent studies have fully confirmed the conclusions expressed in that paper.

Throughout the rest of the area occupied by the Wilcox to the west and southwest as far as the Mexican border it has not yet been found feasible to subdivide the deposits except in a small area in southwestern Texas, where Trowbridge[6] has recently proposed dividing them, in ascending order, into the Indio, Carrizo, and Bigford formations. The oldest of these, the Indio, contains oyster beds and marine Foraminifera, as well as lignite and poorly preserved plants. The plants, of which a considerable number have been satisfactorily identified, are distinctly younger than the known lower Wilcox floras found in the eastern part of the Mississippi embayment—that is, in the Ackerman formation of the eastern Gulf area. These Indio plants could be considered as representing either the Holly Springs or the Grenada epoch of the Mississippi succession. The Indio formation is overlain in southwestern Texas by the transgressive Carrizo sandstone, which as traced toward the Rio Grande merges into the lithologically dissimilar Bigford formation. Both the Carrizo and the Bigford formations have furnished a considerable flora, which is of sufficient variety and precision to prove that they are of upper Wilcox age and is in striking contrast to the flora found near the base of the Mount Selman, the lowest formation of the overlying Claiborne group, in the same area.

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[4] Berry, E. W., Additions to the flora of the Wilcox group: U. S. Geol. Survey Prof. Paper 131, pp. 1-21, 1922.

[5] Berry, E. W., Erosion intervals in the Eocene of the Mississippi embayment: U. S. Geol. Survey Prof. Paper 95, fig. 27, 1915.

[6] Trowbridge, A. C., A geologic reconnaissance in the Gulf Coastal Plain of Texas near the Rio Grande: U. S. Geol. Survey Prof. Paper 131, pp. 85–117, 1922.

As the foregoing brief sketch makes clear, nothing has thus far been discovered corresponding to the conditions found in Bexar and Bastrop counties, and there is no known paleobotanic evidence of the presence of lower Wilcox sediments in the Coastal Plain of Texas, or, in fact, anywhere west of Mississippi River.

The distribution of the plants that form the basis of the present contribution is shown in the accompanying table, from which it will be seen that several of these plants, in their distribution in other regions, are strongly suggestive of a greater age than the Wilcox. There are two alternative conclusions—either that this flora indicates a Midway age, or that it represents an early Wilcox flora that was more ancient than the flora of the Ackerman formation of the eastern Gulf area, which, as previously stated, represents the upper Nanafalia and all of the Tuscahoma of the Alabama section. Perhaps a third possibility might be added, namely, that it may represent a flora that lived in central Texas during the time which there is reason to think intervened between the deposition of the known Midway and that of the known Wilcox in the region to the east of central Texas.

I know of no method by which this question can be conclusively settled at the present time, as the Midway has never furnished satisfactorily determinable plant fossils. In 1910 I collected three species of dicotyledonous leaves from the Porters Creek Midway near Middleton, Tenn., and one of these appears to represent the Vermejo species *Ficus leei* Knowlton.[7] In 1921 Bruce Wade collected five species of plants near the base of the Porters Creek clay in Carroll County, Tenn. None of these are sufficiently well preserved to be satisfactorily determined, although one represents a fern, probably referable to the genus *Dryopteris*, and another suggests *Asimina eocenica*, which is one of the common forms at Earle and Sayersville, Tex. My own preference, which I can not say amounts to a conviction, would be to regard the flora under discussion as of Midway age. If it is really early Wilcox, as the geologists who have studied the areal relations of the Midway and Wilcox in Texas are inclined to consider it, it is of sufficient importance to merit the present discussion.

I have reproduced in Figure 8 a sketch map published originally in 1915,[8] showing the areal distribution of the lower, middle, and upper Wilcox floras. No exceptions to this interpretation have been discovered during the last 10 years unless the florules found at Earle and Sayersville form such an exception, and the abundant evidence of the transgressive character of the middle and upper Wilcox in Texas is one of the strongest reasons for considering these florules to be of Midway age.

If the Earle and Sayersville florules represent early Wilcox time, and I am frank to admit that they may, they indicate the probability that there may be other and similar areas in the western Gulf region that were not completely transgressed by the later Wilcox, which is the only part of the Wilcox that has been paleobotanically recognized in that whole region.

Such of the forms found at Sayersville as warrant the space are discussed in the following pages. The subjoined table presents the known distribution of the species found at Earle and Sayersville.

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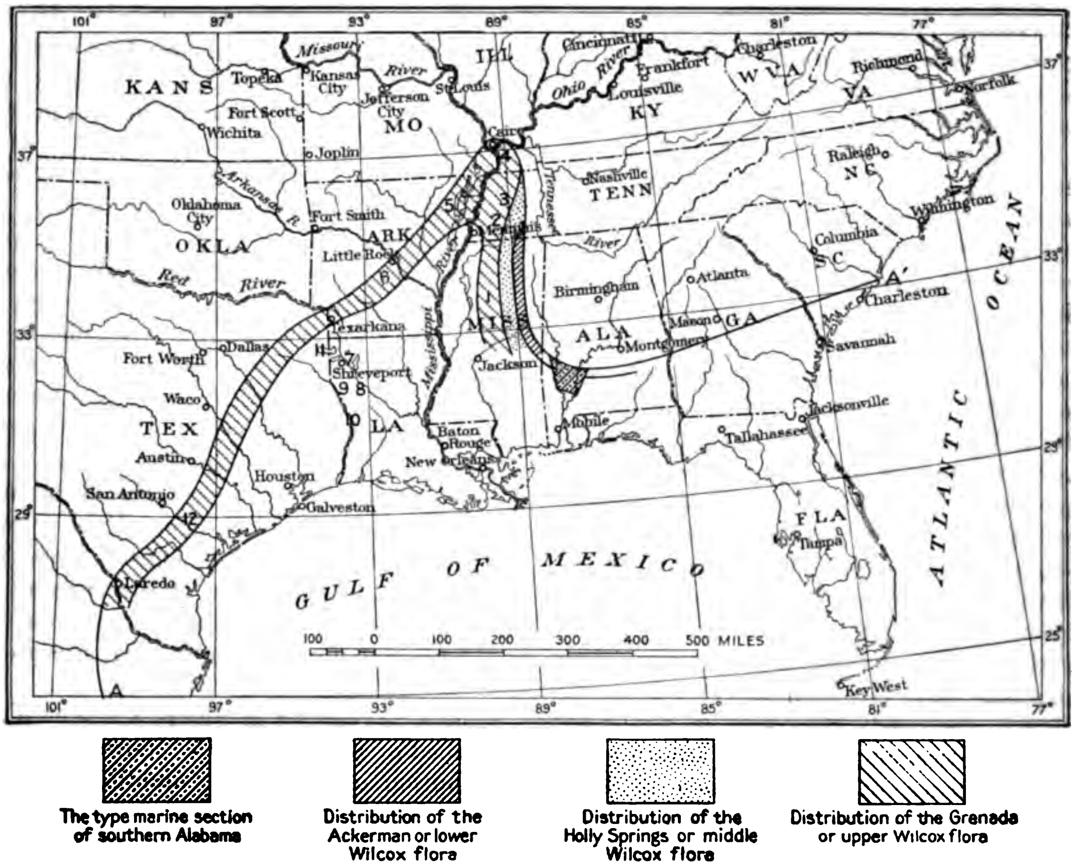
[7] Knowlton, F. H., Fossil floras of the Vermejo and Raton formations of Colorado and New Mexico: U. S. Geol. Survey Prof. Paper 101, p. 261, pl. 39, figs. 1-6; pl. 40, figs. 1, 2, 1918.

[8] U. S. Geol. Survey Prof. Paper 95, fig. 29, 1915.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101° 97° 93° 89° 85° 81° 77°
37° 33° 29° 25°
The type marine section of southern Alabama
Distribution of the Ackerman or lower Wilcox flora
Distribution of the Holly Springs or middle Wilcox flora
Distribution of the Grenada or upper Wilcox flora

FIGURE 8.—Sketch map showing areal relations of the Wilcox floras. A–A', Maximum extent of the Wilcox transgression. Localities at which upper Wilcox species have been collected: 1, Grenada, Miss.; 2, Somerville, Tenn.; 3, near Trenton, Tenn.; 4, Wickliffe and Boaz, Ky.; 5, Bolivar Creek, Hardys Mill, and other localities on Crowleys Ridge, Ark.; 6, Benton and Malvern, Ark.; 7, several localities at or near Shreveport, La.; 8, Coushatta, La.; 9, around Mansfield and Naborton, La.; 10, Sabine River; 11, Old Port Caddo Landing, Tex.; 12, Calaveras Creek, Tex.

Distribution of florules found at Earle and Sayersville, Tex.

	Earle.	Sayersville.	Lower Wilcox.	Middle Wilcox.	Upper Wilcox.	Raton formation.	Denver formation.	Fort Union formation.	Hanna formation.	Mesaverde formation.	Laramie formation.	Lance formation.	Dawson arkose.
Asimina eocenica	×	×					×	×	×	(?)			
Asplenium primero		×				×							
Cinnamomum affine	×										×		
Dolichites deusseni	×												
Ficus post-trinervis		(?)									×		
Ficus denveriana	×				×	×	×	×			(?)	×	
Ficus occidentalis	×		×		×	×	×						
Ficus sp	×			×									
Laurus wardiana	×	×									×		(?)
Mespilodaphne precoushatta		×											
Platanus aceroides latifolia	×					×							
Pourouma texana	×	×											
Rhamnus marginatus apiculatus		(?)	×	×	×								
Rhamus sp		×											
Sapindus? sp		×											
Terminalia hilgardiana	×	×	×	×	×	×							
Terminalia lesleyana		×	×	×	×	×							
Viburnum sp		×											

Asplenium? primero Knowlton.

Plate XXIII, Figure 1.

Asplenium? primero Knowlton, U. S. Geol. Survey Prof. Paper 101, p. 285, pl. 44, fig. 4, 1917.

This species was based on the single specimen figured by Knowlton, which came from the Raton formation at Primero, Colo. It is described as follows by Knowlton:

> Frond broadly lanceolate in general outline, twice pinnatifid; pinnae alternate, approximate, the lower ones lanceolate, the middle and upper ones linear, all decurrent on the rachis; lower pinnae deeply cut into numerous acute teeth, these becoming less and less marked until in the upper part they are merely slight indentations or at the extreme tip are wholly absent; nervation relatively simple, consisting of a strong midrib or secondary rachis in the pinnae, from which arise secondary branches passing to the tips of the segments or teeth, each of these again with from two to four pairs of simple branches.

A single specimen from Sayersville appears to represent a portion of the distal part of a pinna of this species. The venation is obscure, but the size and disposition of the pinnules and their characteristically toothed margins render the identification satisfactory. There are eight species of ferns recorded from the Wilcox, two of which have been referred to the genus *Asplenium*, but both of these are quite unlike *Asplenium? primero.*

Mespilodaphne precoushatta Berry, n. sp.

Plate XXIII, Figure 2.

Leaves of medium size, relatively broad, oval in general outline, widest medianly, and tapering about equally to the apex and base. Apex cuneate. Base acute. Margins entire, rather regularly and evenly rounded. Texture coriaceous. Length about 9.25 centimeters, maximum width about 4.1 centimeters. Petiole long and stout, about 2 centimeters in length. Midrib stout, prominent. Secondaries mediumly stout and prominent, eight or nine somewhat irregularly spaced pairs; closely spaced and opposite in the base, less closely spaced and subparallel to about the middle, above which they are about twice as far apart; they diverge from the midrib at angles of more than 45° and are camptodrome in the marginal region. Occasionally a subsecondary runs midway between and subparallel to the adjacent secondaries in the apical part of the leaf, where the true secondaries are more widely spaced, and one basal secondary shows abnormal branching. An apparently characteristic feature of this species is the crowding of the lower secondaries in the basal part of the leaf. The tertiaries are thin, transverse, and either percurrent or anastomosing.

This well-marked species appears to have been the immediate precursor of the rather abundant late middle and upper Wilcox species *Mespilodaphne coushatta* Berry.[9] It differs from that species in its larger size, slightly more coriaceous texture, relatively shorter petiole, more numerous secondaries, less frequently anastomosing tertiaries, and basal crowding of the secondaries. It is confined to the locality at Sayersville, in Bastrop County.

Terminalia lesleyana (Lesquereux) Berry.

Plate XXIII, Figure 3.

Magnolia lesleyana Lesquereux, Am. Philos. Soc. Trans., vol. 13, p. 421, pl. 21, figs. 1, 2, 1869; Tertiary flora, p. 248, pl. 44, figs. 1–3, 1878. Knowlton, U. S. Geol. Survey Prof. Paper 101, p. 313, pl. 82, figs. 1–2, 1918.

Terminalia lesleyana Berry, U. S. Geol. Survey Prof. Paper 91, p. 323, pl. 89, fig. 4, 1916.

The type horizon for this species was the lower Wilcox or Ackerman formation in Mississippi, but it has since been found to range into the middle and upper Wilcox and was a fairly common coastal tree along the shores of the Wilcox Mississippi embayment. It has also been recorded from the Raton formation of Colorado and New Mexico by both Lesquereux and Knowlton. I regard the Raton formation as older than the Wilcox, and it is therefore not surprising that this species should turn up in the present association in an area nearer the western occurrences than it has been hitherto found.

As Knowlton accepts Lesquereux's reference of this species to the genus *Magnolia* a few comments may not be out of place. Hilgard submitted his early collections from Mississippi, from what has since been named the Ackerman formation, to Lesquereux, who identified the present species as a *Terminalia*, and it was so listed in Hilgard's report.[10] When the similar leaves that have since been considered to represent this species were collected in the Fishers Peak region of New Mexico from what has since been named the Raton formation. Lesquereux considered them identical with the European fossil species *Terminalia radobojensis* Heer. Subsequently Lesquereux transferred them to the genus *Magnolia*, comparing them with the existing species *Magnolia tripetala*. When I was preparing the report on the Wilcox flora I compared these fossil leaves with those of the existing species of both *Magnolia* and *Terminalia* and reached the conclusion that in every essential respect they differed from the former and resembled the latter. I therefore transferred them back to *Terminalia* thus confirming Lesquereux's original determination. I also reached the conclusion that a considerable number of fossil species which masquerade in the literature of paleobotany as *Magnolia* probably do not represent that genus.

---

[9] Berry, E. W., The lower Eocene floras of southeastern North America: U. S. Geol. Survey Prof. Paper 91, p. 307, pl. 80, fig. 6; pl. 87, fig. 3, 1916.

[10] Hilgard, E. W., Report on the geology and agriculture of the State of Mississippi, p. 113, 1860.

Terminalia lesleyana is not, in my judgment, particularly like *Magnolia tripetala* in any features. Although smaller, it is stouter, coarser, and smoother, with a different shape and different base from any of the true Magnolias. The midrib is very stout, as are also the fewer secondaries—in fact, the venation is not that of the genus *Magnolia*. On the other hand, in all the features that are available for comparison it resembles the leaves of several recent American species of *Terminalia*, as well as certain European Tertiary species that have been referred to that genus. Moreover, American Tertiary floras of warmer climatic aspects contain several other species of *Terminalia*, in more than one locality represented by fruits that supplement and corroborate the identifications of the leaves.

Terminalia, represented by one species founded on fruits and two founded on leaves, is common in the Wilcox of the Mississippi embayment, and it is also represented in that region throughout the middle (Claiborne) and upper (Jackson) Eocene.

Terminalia lesleyana occurs at the Sayersville locality, in Bastrop County, but the associated *Terminalia hilgardiana* is present at both Sayersville and Earle, and both species are found throughout the lower, middle, and upper Wilcox of the eastern Gulf region.

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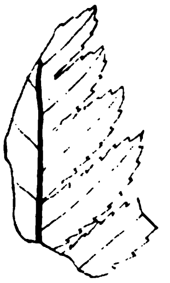

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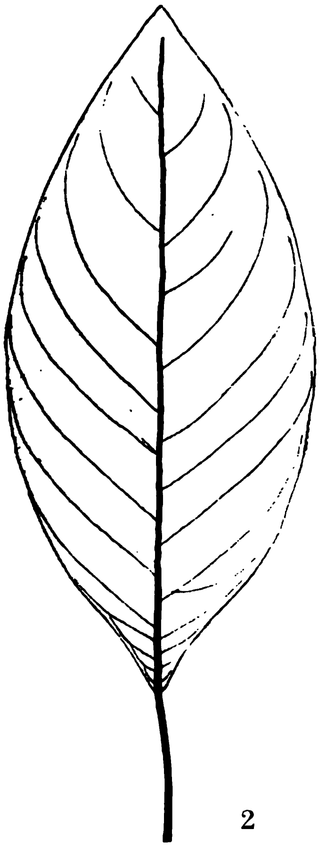

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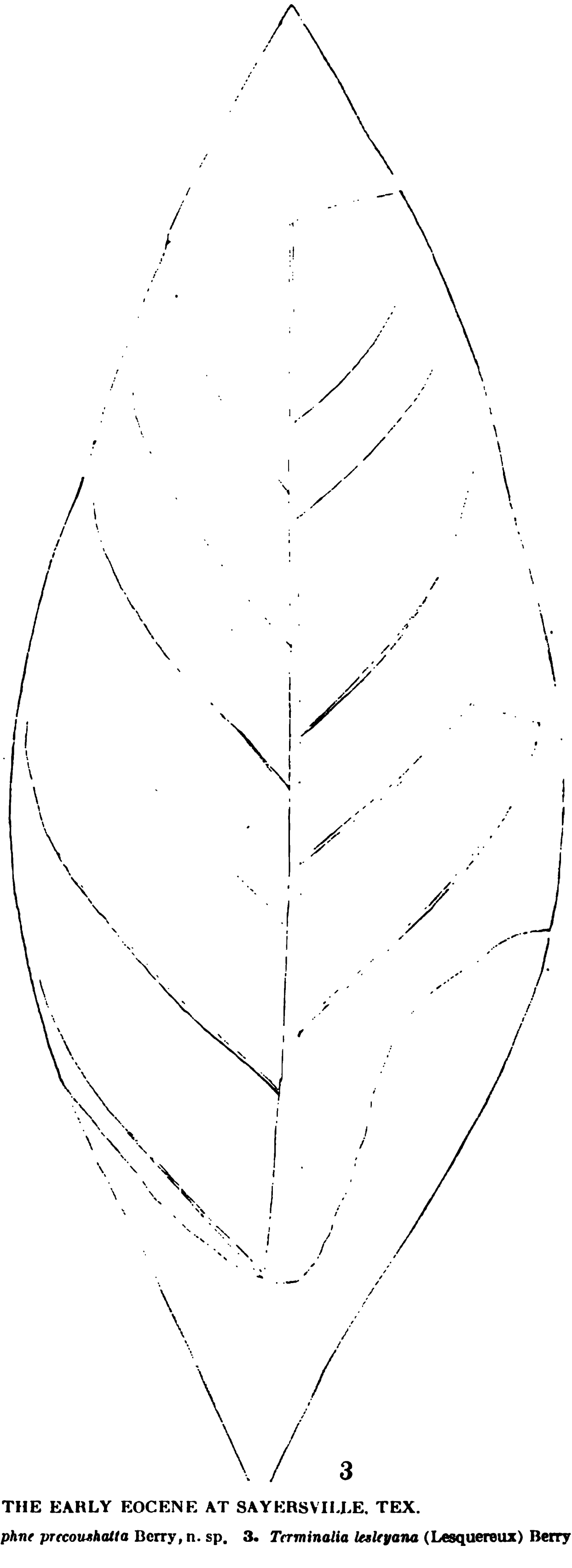

3

FOSSIL PLANTS FROM THE EARLY EOCENE AT SAYERSVILLE, TEX.

1. *Asplenium? primero* Knowlton. 2. *Mespilodaphne precoushatta* Berry, n. sp. 3. *Terminalia lesleyana* (Lesquereux) Berry.

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Professional Paper 132—F

RELATIONS OF THE WASATCH AND GREEN RIVER FORMATIONS IN NORTHWESTERN COLORADO AND SOUTHERN WYOMING

WITH NOTES ON OIL SHALE IN THE GREEN RIVER FORMATION

BY

J. D. SEARS AND W. H. BRADLEY

Published November 6, 1924

Shorter contributions to general geology, 1923-1924

(Pages 93-107)

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RELATIONS OF THE WASATCH AND GREEN RIVER FORMATIONS IN NORTHWESTERN COLORADO AND SOUTHERN WYOMING, WITH NOTES ON OIL SHALE IN THE GREEN RIVER FORMATION.

By J. D SEARS and W. H. BRADLEY.

INTRODUCTION.

PURPOSE AND SCOPE OF THE REPORT.

Since the early geologic explorations of Powell, King, and Hayden the Eocene deposits of the Rocky Mountain and Plateau provinces have been the object of much attention by stratigraphers. More widespread interest in these deposits has been stimulated by the discovery of vast quantities of oil shale in the Green River formation of Wyoming, Colorado, and Utah.

The writers have had an opportunity to see the depositional edge of the Eocene formations on the northeast flank of the Uinta Mountains and to study the significance of their character along this margin as compared with their character farther out in the basin. The purpose of this report is to describe the lithology, areal distribution, and interfingering of the Wasatch and Green River formations in northwestern Colorado and southern Wyoming and to draw conclusions as to their source of material, mode of origin, time relations, and proper nomenclature. The method and place of deposition are of special importance in considering the Green River formation, as they largely determine the relative richness of the oil shale found in that formation.

EARLIER INVESTIGATIONS.

The area discussed in this paper is part of the region explored half a century ago by Hayden,[1] Powell,[2] Hague and Emmons,[3] and King.[4] Hayden named the Green River and Wasatch formations, and the latter name thus has priority over the "Vermilion Creek series" of King and the "Bitter Creek group" of Powell. In 1907 the western part of the Little Snake River coal field was examined by Ball.[5] In 1907 and 1908 Schultz [6] mapped in detail the coal-bearing formations of the Rock Springs uplift. As a result of this work and of later reconnaissance to the south and east, he prepared a map [7] covering most of the area described in this paper.

FIELD WORK.

In 1921 and 1922 a large part of Moffat County, Colo., and a few townships in southern Sweetwater County, Wyo., were examined by parties in charge of the senior writer. He was assisted in 1921 by K. K. Landes, in 1922 by James Gilluly, and in both seasons by the junior writer. Mapping was done largely by means of plane tables and telescopic alidades, on a system of triangulation extended westward and northwestward from the Craig quadrangle, Colorado. Isolated structural and areal features were mapped by means of stadia or pace traverses according to the degree of refinement desired. The mapping was tied to section corners at numerous points.

The geologic map (Pl. XXIV) accompanying this report is compiled from the work of Ball,

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[1] Hayden, F. V., U. S. Geol. Survey Terr. Third Ann. Rept., 1869.

[2] Powell, J. W., Report on the geology of the eastern portion of the Uinta Mountains, U. S. Geol. and Geog. Survey Terr., 2d div., 1876.

[3] Hague, Arnold, and Emmons, S. F., U. S. Geol. Expl. 40th Par Rept., vol. 2, 1877.

[4] King, Clarence, idem, vol. 1, 1878.

[5] Ball, M. W., The western part of the Little Snake River coal field, Wyo.: U. S. Geol. Survey Bull. 341, pp. 243-255, 1909.

[6] Schultz, A. R., The northern part of the Rock Springs coal field, Sweetwater County, Wyo.: U. S. Geol. Survey Bull. 341, pp. 256-282, 1909; The southern part of the Rock Springs coal field, Sweetwater County, Wyo.: U. S. Geol. Survey Bull. 381, pp. 214-281, 1910.

[7] Schultz, A. R., Oil possibilities in and around Baxter Basin, in the Rock Springs uplift, Sweetwater County, Wyo.: U. S. Geol. Survey Bull. 702, pl. 1, 1920.

Schultz, and Sears. The location of the area is shown in Figure 9.

ACKNOWLEDGMENTS.

The writers gratefully acknowledge the cordial assistance and hospitality given by the local ranchers, especially Messrs. Sparks, Crozier, and Grounds.

TOPOGRAPHY.

In the southwestern part of the area mapped Cold Spring Mountain and other ridges on the north flank of the Uinta Mountains rise to an altitude of about 8,500 feet above sea level. To the north, northeast, and east is the Green River Basin, separated by the Rock Springs uplift into the Bridger Basin on the west and the Washakie and Sand Wash basins on the east. Although the Green River Basin is of less altitude than the Uinta Mountains it contains here and there high cliffs and isolated peaks; the highest point is Diamond Peak, 9,925 feet above sea level.

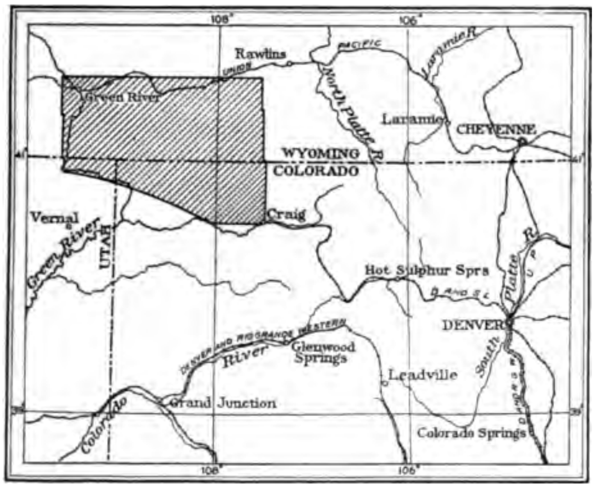

FIGURE 9.—Index map showing location of area in northwestern Colorado and southern Wyoming.

The major stream of the area mapped is Green River, which flows southward along its western margin. Green River, with its main tributaries, Bitter and Vermilion creeks, drains the Rock Springs uplift and a large part of the Washakie Basin. Across the southeast corner of the area runs Little Snake River, which, with its tributaries, Sand and Powder washes, drains the Sand Wash Basin and part of the Washakie Basin.

STRATIGRAPHY.

WASATCH FORMATION.

The Wasatch deposits were named by Hayden[8] because of their excellent exposures on the eastern slopes of the Wasatch Mountains. Their lithologic character in that region is illustrated by his brief description of their appearance in Echo and Weber canyons, Utah, where the formation consists of 1,500 to 2,000 feet of conglomerate. In a later report Hayden[9] described this section more fully, noting the large size and well-rounded shape of the boulders and the predominant red color of the sandstones that make up the lower 500 to 800 feet of the formation. He noted also the rapid lateral changes near the base from fine sand to coarse conglomerate.

It is perhaps unfortunate that the name was taken from the Wasatch Mountains, where the formation has a lithologic character very different from that shown in most other areas. Hayden[10] described the Wasatch at Carter Station, Wyo., as consisting of pink, red, and purple indurated sandy clays, alternating with gray and reddish sandstones; this description is more applicable to the formation throughout most of its area of distribution. Hayden believed that the beds were deposited in large fresh-water lakes.

Within the area mapped by the writers in 1921–22 the Wasatch consists chiefly of variegated clay shale and irregular, crudely bedded sandstone. The predominant colors of the clay shale are red and gray, commonly banded with yellow, lavender, pink, brown, pale green, drab, and other shades. Most of the sandstone is gray, buff, or dark brown; a few beds are white, pink, or red. The materials of the sandy beds range in size from very fine grains to coarse grits, and locally the sandstone grades into conglomerate carrying boulders as much as 6 feet in diameter.

In the Vermilion Creek basin the middle part of the Wasatch contains a few beds of coal, fissile carbonaceous shale, shell marl, and many more beds of sandstone than elsewhere in the field.

In general the Wasatch formation weathers into typical badlands that support little or no vegetation. Topography of this kind is varied

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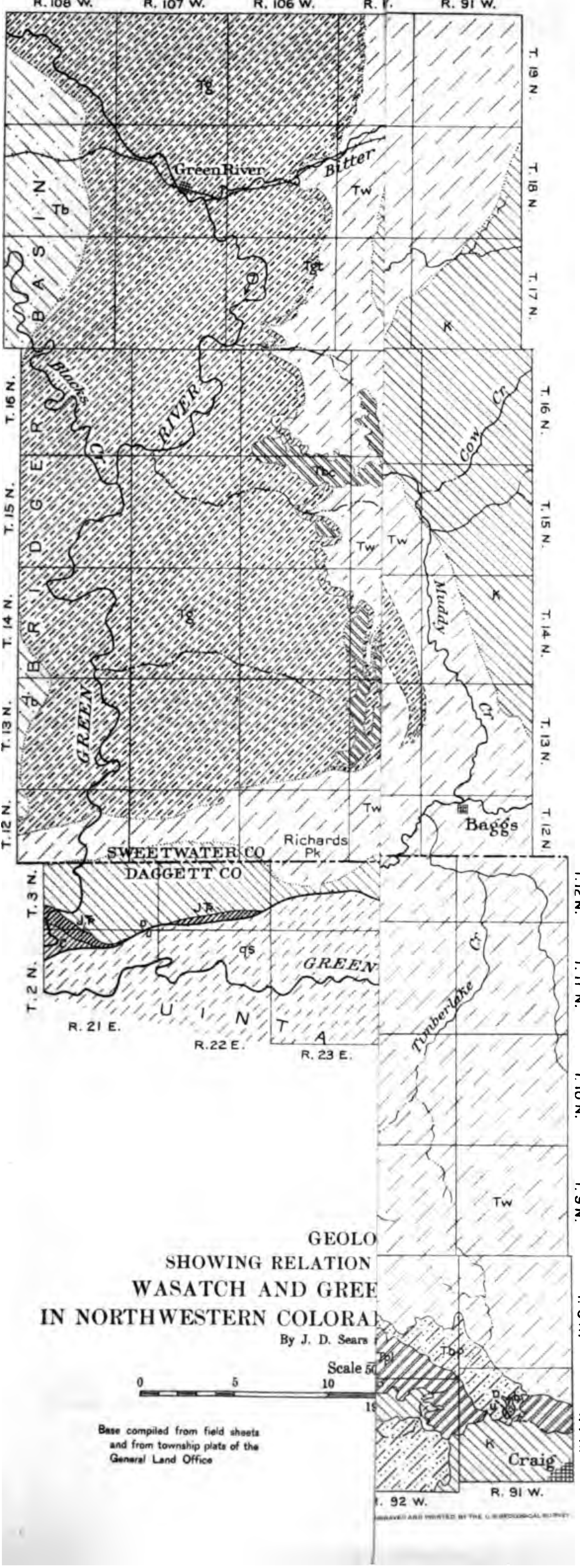
[8] Hayden, F. V., U. S. Geol. and Geog. Survey Terr. Third Ann. Rept., p. 91, 1869.

[9] Idem, Fourth Ann. Rept., pp. 147, 155–156, 1871.

[10] Idem, p. 147.



GEOLO

SHOWING RELATION

WASATCH AND GREE

IN NORTHWESTERN COLORA

By J. D. Sears

Scale 5

Base compiled from field sheets
and from township plats of the
General Land Office

ENGRAVED AND PRINTED BY THE U.S.GEOLOGICAL SURVEY

EXPLANATION

SEDIMENTARY ROCKS

Miocene(?)

Tbp

Browns Park formation

(Mostly soft chalk-white sandstone; beds of chert; conglomerate at base)

UNCONFORMITY

Tbc

Bishop conglomerate

(Water-worn and subangular pebbles and boulders in finer gravel and sand matrix. In writer's opinion equivalent to basal conglomerate of Browns Park formation)

UNCONFORMITY

Eocene

Tb

Bridger formation

(Ash-gray and greenish clay shale; gray, buff, and blue-green sandstone; light-gray and white marl, limestone, and chert; conglomerate)

UNCONFORMITY LOCALLY

Tg Tgt Twc Tw

Green River and Wasatch formations

(Green River formation: *Gray fissile shale and oil shale, gray clay shale, gray and buff sandstone and limestone, oolitic layers and alga reefs;* Tg, *chiefly Laney shale member;* Tgt, *Tipton tongue, which interfingers with Wasatch formation.* Wasatch formation: *Variegated clay shale, gray, buff, and pink sandstone, grit, conglomerate, and coal beds;* Tw, *main body of Wasatch;* Twc, *Cathedral Bluffs tongue, which interfingers with Green River formation)*

UNCONFORMITY

TERTIARY

Eocene(?)

Tpl

Post-"Laramie" formation

(Gray and brown sandstone; gray and drab shale, coal beds; conglomerate at base)

UNCONFORMITY

TERTIARY(?)

K

Gray, white, and brown sandstone; coal beds; gray shale; conglomerate; variegated clay shale

CRETACEOUS

JTr

Gray thin-bedded limestone; white cross-bedded sandstone; red, gray, and drab shale

TRIASSIC AND JURASSIC

C

White and gray limestone, at places cherty; white and buff quartzite; shale, sandstone, and thin coal beds

UNCONFORMITY

CARBONIFEROUS

qs

Great thickness of red quartzite and sandstone; some shale and white sandstone and quartzite

PRE-CARBONIFEROUS

IGNEOUS ROCKS

Miocene(?)

b

Basalt

TERTIARY

Anticlinal axis

Fault

(D, downthrow; U, upthrow)

Boundaries taken from U. S. Geol. Survey Bull. 702, by A. R. Schultz, and from Bull. 341, by M. W. Ball

Location of measured section referred to in the text

by low escarpments and benches where the sandstone is comparatively resistant.

GREEN RIVER FORMATION.

Remarkable exposures along Green River led Hayden [11] to apply the name of that stream to the series of shale and sandstone overlying his Wasatch "group." The type locality of the formation is at the town of Green River, Wyo., where, according to Winchester,[12] an incomplete section has a thickness of 755 feet. Other sections near by,[13] in Tps. 17 and 19 N., R. 106 W., show a thickness of approximately 1,350 feet. In all these sections a coarse, massive brown sandstone, 125 to 245 feet thick (the "Tower sandstone" of Powell), is included in the top of the formation. The remainder of the formation at the type locality consists almost entirely of finely laminated shale, some of which is rich oil shale. A few beds of thin platy sandstone and sandy shale occur at wide intervals in these sections. A very striking feature of the Green River in this part of the field is its bluish-white color on weathered surfaces.

Farther southeast, in the outcrops surrounding the Washakie and Sand Wash basins, the formation shows a somewhat different lithology. The "Tower sandstone" of Powell was not recognized by the writers in the southern part of this area, but it may be represented by one or more of the sandstones in the upper part of their Green River. The contact between this formation and the overlying Bridger was difficult to determine; it was drawn in the field at the horizon considered to mark most plainly a change in conditions of sedimentation. This mapping includes at the top of the Green River about 135 feet of beds that resemble somewhat the overlying as well as the underlying rocks. The Green River in this part of the field is about 1,200 feet thick and consists principally of finely laminated shales, many of which are very limy, and some beds of low-grade oil shale. The formation weathers to a characteristic buff color. In the upper 500 or 600 feet there is a greater amount of clay shale and thin-bedded to massive sandstone. A few thin beds of oolitic limestone, generally silicified, and calcareous alga reefs are scattered through the section.

The Green River formation is peculiarly resistant to weathering and rises in high, steep cliffs of monotonous buff, gray, or bluish-white tints, contrasting sharply with the brightly colored badlands of the Wasatch. Almost as striking is the contrast between the Green River and the overlying Bridger, which weathers into fantastic badlands of ash or bluish gray, varied by dark-green and light-bluish sandstones and a few patches of red and orange-colored clay shale.

STRUCTURE.

The southern margin of the field is the north flank of the Uinta Mountain-Axial Basin arch. West of Little Snake River the Eocene beds, dipping away from the mountains, rest with marked angular unconformity upon the upturned edges of Mesozoic rocks, showing that uplift of the Uinta region both preceded and followed Eocene deposition. Farther southeast no angular unconformity is found below the Wasatch and Green River, a fact which indicates that movement of the Axial Basin anticline began after the end of Eocene time.

North of this great uplift is the broad Green River Basin, which in the area here mapped is divided by the north-south Rock Springs uplift into two synclinal depressions. The western depression, known as the Bridger Basin, is partly within this area. The eastern depression is separated by one or two east-west arches into the Washakie Basin on the north and the Sand Wash Basin on the south.

The present southern edge of the Eocene outcrops is determined partly by the original limits of deposition and partly by structure. At the southwest it is marked in part by the great Uinta fault, which extends for many miles westward from the northwest corner of Colorado; some if not all of the movement along this fault was post-Wasatch. It is possible that the fault between the Cretaceous and the Wasatch rocks, extending from Diamond Peak southeastward to a point beyond East Fork of Vermilion Creek, is a continuation of the Uinta fault, but their relation is concealed by recent débris.

From Vermilion Creek southeastward to Sand Creek the margin of Eocene deposits is marked by a zone of en échelon faults and sharp anticlines. These and other faults farther out in the basin have no bearing on the character and relations of the Wasatch and Green River and need not be described here.

---

[11] Hayden, F. V., U. S. Geol. and Geog. Survey Terr. Third Ann. Rept., p. 90, 1869.

[12] Winchester, D. E., Oil shale of the Rocky Mountain region: U. S. Geol. Survey Bull. 729, p. 125, 1923.

[13] Idem, pp. 124-126.

ORIGIN AND RELATIONS OF THE WASATCH AND GREEN RIVER FORMATIONS.

THE UINTA MOUNTAINS AS A SOURCE OF MATERIAL.

Powell[14] noted the occurrence of thick conglomerates in the basal part of his "Bitter Creek group" (Wasatch formation) on the north side of the Uinta Mountains from Richards Peak, Wyo., to a point east of Bruce Mountain, Colo. The conglomerate consists of boulders and pebbles of sandstone and limestone; in the vicinity of Richards Peak the limestone boulders contain Jurassic fossils. From these facts Powell inferred that in Wasatch time erosion of the Uinta Mountains had in places reached the Carboniferous rocks; that the conglomerate referred to was formed from sandstone and limestone of Mesozoic age, and, to a lesser extent, of Carboniferous age; and "that the badland rocks of Mesozoic age were carried from the Uinta region and redistributed as badland beds of the Bitter Creek period."[15] Powell[16] noted also that near the Uinta uplift the Green River formation "is much thickened, and the shales are replaced by sandstones and conglomerates of fine pebbles"; from this he inferred that the Green River was "derived from the Uinta region, and that the material was supplied from limestones and sandstones of Carboniferous age."

Additional evidence pointing to the Uinta Mountains as a source of material was collected by the writers in 1922. Conglomerates in both the Wasatch and the Green River are thickest and carry the largest boulders near the mountains and thin rapidly toward the basin. The most conspicuous example is at Sugarloaf Butte, in secs. 15 and 16, T. 11 N., R. 101 W., where there is in the lower part of the Wasatch an alternating series, 150 to 200 feet thick, of very coarse conglomerate, grit, and lenses of coarse cross-bedded friable buff to white sandstone. Most of the boulders are well rounded by stream action, but some are angular and subangular; the largest boulders are 6 feet in diameter. (See Pl. XXV, *A*.) This notable aggregation of coarse detritus, in which there is only the crudest kind of stratification, grades laterally within less than a mile to the north and east into carbonaceous shale, shell marl, and coarse but regularly bedded sandstone—the typical Wasatch assemblage of this vicinity. The interfingering of these several types is clearly exposed eastward in the bluffs along Talamantes Creek and to the north in deep tributary gulches. There can be no doubt that the material was derived from the Uinta uplift, as the conglomerate thins away from the mountains and consists principally of gray cherty limestone identical with the massive Carboniferous limestone now exposed high on the flank of Cold Spring Mountain, less than 2 miles to the southwest. Evidently the Carboniferous rocks of the uplift were being eroded during at least a part of Wasatch time.

Westward from Sugarloaf Butte the Wasatch contains near its base several beds of conglomeratic sandstone consisting of abundant white sugary-textured quartzite pebbles and boulders as much as 8 inches in diameter in a white or gray sandy matrix. These white quartzites are very similar to the Weber and older Pennsylvanian quartzitic sandstones exposed in the Uinta Mountains. Eastward from Sugarloaf Butte as far as East Fork of Vermilion Creek conglomerates in the lower Wasatch are characterized by pebbles of black chert; the source of the chert is unknown, but the pebbles strongly resemble those of the Dakota in color, roundness, and high polish, and they may have been reworked from that formation.

Eastward from Godiva Ridge several conglomeratic sandstones near the base of the Wasatch contain many well-rounded chert pebbles less than half an inch in diameter; these pebbles, predominantly white and to a lesser extent red and black, may have been derived either from the Uinta Mountains or from the Park Range, to the east.

The development of conglomerate close to the mountains is illustrated also in the Green River formation. Along Canyon Creek from sec. 18, T. 12 N., R. 101 W., westward to Pine Mountain the upper 300 feet of the Tipton tongue of the Green River formation is represented by massive medium to coarse grained sandstones separated by very thin partings of hard greenish shale. In these sandstones, especially in the upper ones, are zones of pebbles and boulders as large as 6 inches in diameter, of white and brown quartzite, angular red chert, hard shale, and cherty limestone; a few boulders consist of red quartzite lithologically identical with the red quartzite that forms the core of the Uinta Mountains. Schultz[17] noted these conglomeratic sandstones on Canyon Creek and says: "Upstream on Ruby Creek toward the mountains the percentage of conglomerate and the size of the pebbles rapidly increase. Within a mile boulders as large as 2 feet are encountered." Northward from the Canyon Creek coal mine, in sec. 17, T. 12 N., R. 101 W., the conglomeratic sandstone grades laterally into gray fissile shale that is characteristic of the Tipton tongue.

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[14] Powell, J. W., Report on the geology of the eastern portion of the Uinta Mountains, pp. 162–164, U. S. Geol. and Geog. Survey Terr., 2d div., 1876.

[15] Idem, p. 165.

[16] Idem, p. 166.

Another type of evidence pointing to the Uinta Mountains as a source of material may be summarized as follows. An erosional window in the Browns Park formation, in T. 9 N., R. 100 W., exposes the Bridger resting with marked angular unconformity upon Mancos and older Mesozoic rocks dipping northeastward on the flank of the Uinta Mountain arch. The Bridger is very conglomeratic, the boulders consisting largely of gray cherty limestone containing Carboniferous fossils. Inasmuch as a few miles farther north there is no angular unconformity between the Bridger and Green River, the fact that in T. 9 N., R. 100 W., the Bridger rests directly upon Mesozoic rocks seems to show that the Wasatch and Green River were not deposited this far south, and that the Bridger was laid down as an overlap beyond the margins of the older Eocene beds. This conclusion, together with the conglomeratic nature of the Bridger, indicates that the east end of the Uinta Mountains was never buried under Eocene beds but was the site of erosion that furnished the Eocene sediments. On the other hand, it seems probable that the Wasatch and Green River formations (and possibly the Bridger) of the Green River and Uinta basins were continuous around the east end of the mountains; this inference is drawn from the narrow interval (14 miles) now separating the northern and southern Wasatch and Green River outcrops east of Cross Mountain and from the lack of angular unconformity between Wasatch and Cretaceous rocks in the Axial Basin anticline, showing that that arch was not uplifted at the earliest until after Green River time.

BROAD VARIATIONS AWAY FROM THE SOURCE.

In addition to the local changes within the formations near the mountains, there are large-scale lateral variations in the sediments farther out in the basin of deposition.

In the basin of Vermilion Creek the upper part of the Wasatch is principally variegated clay shale in which red is the predominant color. The lower part consists largely of gray and buff clay shale and sandstone; it includes also some brightly colored clay shale, a few beds of coal which in places are thick enough to be mined for local use, thin-bedded carbonaceous shale and interbedded shell marl (which superficially resemble the Green River formation), and at least one calcareous alga reef. In the vicinity of East Fork of Vermilion Creek, northeastward from sec. 4, T. 10 N., R. 100 W., a zone of clay shale and sandstone near the top of the lower Wasatch grades laterally into gray fissile shale of Green River appearance. Farther north this zone includes beds of low-grade oil shale; it thickens from about 200 feet in sec. 3, T. 10 N., R. 100 W., to nearly 400 feet in secs. 27 and 28, T. 12 N., R. 99 W. The method of thickening is illustrated at the base of the fissile shale in secs. 34 and 35, T. 11 N., R. 100 W., where a long wedge of papery, low-grade oil shale replaces toward the north a band of gray and buff clay shale, and the whole Green River zone thickens 100 feet in about a mile. Similar examples were noted elsewhere along the outcrop.

Thus the Wasatch is split northward into two parts by a wedge of very different material. The thickness of the lower part is unknown, as the base is not exposed. The upper part, called by Schultz[18] the Cathedral Bluffs red beds member of the Green River formation, is 1,200 feet thick at Lookout Mountain and 600 feet thick northwest of the Washakie Basin; westward and northwestward, according to Schultz, it merges laterally into typical Green River shale. The wedge of fissile shale and oil shale was named by Schultz[19] the Tipton shale member of the Green River formation.

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[17] Schultz, A. R., Oil possibilities in and around Baxter Basin, in the Rock Springs uplift, Sweetwater County Wyo.: U. S. Geol. Survey Bull. 702, p. 31, 1920.

[18] Idem, p. 28.

[19] Idem, p. 30.

On the east side of the Washakie-Sand Wash depression a similar change northward occurs in the Wasatch. Godiva Ridge is capped by the main body of the Green River formation, which in this area is the Laney shale member. Below this is exposed the entire Wasatch formation, 5,600 feet thick, consisting of brightly colored clay shale and subordinate sandstone, with no beds of Green River type. North of Baggs, Wyo., the Tipton tongue of the Green River enters in the midst of the Wasatch beds, thickens northward, and, encircling the north end of the Washakie Basin, unites with the Tipton to the west. Thus the outcrop of the Tipton tongue has the shape of the letter U with the open side toward the south. The Tipton lake may have extended southward to a line between Baggs and East Fork of Vermilion Creek; and there is a possibility that much of the Cathedral Bluffs tongue of red beds, deposited as this lake retreated, was derived from the east and southeast.

In contrast to the relations described above, Green River deposition on the east rim of the Bridger Basin was evidently not interrupted by a temporary regression of the lake, as the Wasatch and Green River show no interfingering, even close to the mountains. In this area the lake probably reached the foot of the mountains, but as the finely laminated shale and oil shale of the Green River indicate deposition in very quiet water, material must have been carried out from the mountains very slowly if at all.

On the rim of the Washakie-Sand Wash depression the main body of the Green River formation (Laney shale member) undergoes a very gradual northward change. Near the mountains it is prevailingly buff and much of its shale is limy and poor in oil-yielding organic matter. Although sandstones are numerous, only one conglomerate was observed. This conglomerate, about 5 feet thick, contains small subangular pebbles of black and green chert and of coarse-grained red quartzite, some grains of glassy quartz, and a few compact clay balls. The pebbles average a quarter of an inch in diameter; a few pebbles of black chert are an inch in diameter. This conglomeratic lens, near the top of the Laney shale member in T. 9 N., R. 100 W., passes rapidly northward into a coarse-grained sandstone with a limy cement. Just west of Little Snake River, near the center of T. 8 N., R. 97 W., two or three thin beds of coal and numerous beds of partly humified plant remains occur in the Laney shale several hundred feet above the base. The coal beds are bony and very lenticular, ranging from a few inches of carbonaceous material to beds 3 feet thick. Toward the north the Green River formation contains fewer and thinner sandstones, and its buff color changes gradually to the more characteristic bluish-white tone, probably owing to an increasing richness of the oil shale.

NOMENCLATURE.

The early explorers believed that the Green River formation is not only different from the Wasatch in lithology but is also distinctly younger throughout. Such a belief is justified in the Bridger Basin, where the Wasatch was followed by continuous Green River deposition. Farther east, however, in the Washakie-Sand Wash depression, this belief led them to draw the boundary at the base of the beds later named Laney shale member by Schultz, thus including in the Wasatch the deposits here called the Tipton tongue of the Green River formation and the Cathedral Bluffs tongue of the Wasatch formation. The boundary was drawn at the same horizon by Schultz[20] in his reports on the coal fields of the Rock Springs uplift. In a later report, however, Schultz[21] described the northwestward gradation of his Cathedral Bluffs red beds member into shale of Green River type and suggested that his Tipton shale member might die out toward the southeast, causing an interfingering of the two formations. He believed that the Green River west of the Rock Springs uplift is the time equivalent of all beds east of the uplift between the base of the Tipton tongue and the base of the Bridger, and hence he treated the Tipton tongue and the Cathedral Bluffs tongue as members of the Green River formation.

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[20] Schultz, A. R., The northern part of the Rock Springs coal field, Sweetwater County, Wyo.: U. S. Geol. Survey Bull. 341, pp. 256–282, 1909; The southern part of the Rock Springs coal field, Sweetwater County, Wyo.: U. S. Geol. Survey Bull. 381, pp. 214–281, 1910.

[21] Schultz, A. R., Oil possibilities in and around Baxter Basin, in the Rock Springs uplift, Sweetwater County, Wyo.: U. S. Geol. Survey Bull. 702, pp. 25, 28–31, 1920.

Although the time equivalence suggested by Schultz is essentially correct, the writers believe that his classification does not adequately express the time and depositional relations of the Wasatch and Green River. The interfingering of these formations, now proved to exist, may be better indicated by the use of the term "tongue," introduced by Stephenson.[22] The names Cathedral Bluffs tongue of the Wasatch formation and Tipton tongue of the Green River formation are therefore here used to replace the members of Schultz. The relations of these tongues are shown diagrammatically in Figure 10.

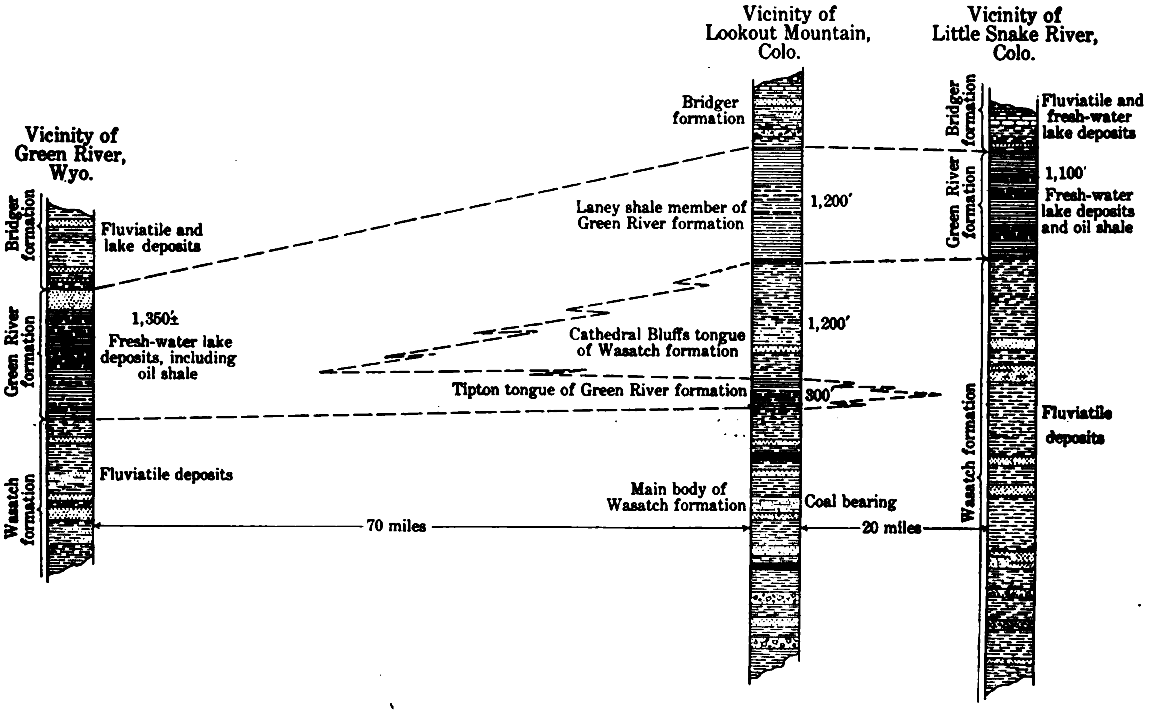
Vicinity of Green River, Wyo.
Bridger formation
Fluviatile and lake deposits
Green River formation
1,350±
Fresh-water lake deposits, including oil shale
Wasatch formation
Fluviatile deposits
70 miles
Vicinity of Lookout Mountain, Colo.
Bridger formation
Laney shale member of Green River formation
1,200'
Cathedral Bluffs tongue of Wasatch formation
1,200'
Tipton tongue of Green River formation
300'
Main body of Wasatch formation
Coal bearing
20 miles
Vicinity of Little Snake River, Colo.
Bridger formation
Fluviatile and fresh-water lake deposits
Green River formation
1,100'
Fresh-water lake deposits and oil shale
Wasatch formation
Fluviatile deposits

FIGURE 10.—Sections from northwest to southeast in the Green River Basin, Wyoming and Colorado, showing interfingering of the Wasatch and Green River formations.

SUMMARY OF GEOLOGIC HISTORY.

The geologic events bearing on the deposition and relations of the Wasatch and Green River in this area may be summarized as follows:

After Cretaceous time the Mesozoic and older rocks were lifted many thousands of feet in the Uinta Mountain arch, and on the north side part of this movement resulted in great faulting. Streams began a vigorous attack on the Mesozoic rocks forming the surface of the arch and carried great amounts of sediment out over the lowlands. Alluvial fans of poorly sorted boulders were built up at the foot of the mountains by torrential streams; flood-plain silts and stream-channel deposits, which later became colored clay shale and coarse, irregular sandstone, were laid down farther out in the basin. Here and there swamp conditions permitted the accumulation of plant remains, which later became carbonaceous shale and coal. To the east and west these deposits of early Wasatch time merged with material brought from the Park and Wasatch ranges. As erosion cut deeper into the mountain mass, older rocks were exposed and fragments of Carboniferous limestone were carried into the basin. Scattered shallow ponds swarmed with organisms such as *Unio* and *Goniobasis*, as is attested by the abundant shell marl interspersed in lenses of finely laminated carbonaceous shale. The increasing thickness of the Wasatch deposits caused an encroachment upon the lower flanks of the mountains, as illustrated on Vermilion Creek by the overlap of the Wasatch upon beds ranging in age from Mesaverde to Twin Creek. East of the Uinta Mountains the Wasatch was laid down upon practically horizontal Cretaceous rocks.

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[22] Stephenson, L. W., Tongue, a new stratigraphic term, with illustrations from the Mississippi Cretaceous: Washington Acad. Sci. Jour., vol. 7, pp. 243-250, 1917.

Over these flood-plain deposits spread gradually a broad, shallow lake. Toward the west this lake reached the foot of the Uinta Mountains; here its transgression marked the end of Wasatch sedimentation, as the lake maintained its position until the end of Green River time. Farther east the margin of the lake was a line between East Fork of Vermilion Creek and Baggs, Wyo. Into the quiet waters of this lake was transported fine sediment, which became mixed with varying amounts of organic matter and formed the gray fissile shale and oil shale of Green River type. Some coarser débris was carried into the edges of the lake, as shown by the conglomerate in the Tipton tongue on Canyon Creek. Meanwhile sedimentation of Wasatch type was continuing over the flood plains not transgressed by the lake.

After the deposition of several hundred feet of shale, forming the Tipton tongue, the margin of the lake gradually receded to a line roughly marked to-day by the axis of the Rock Springs uplift. Within the limits of the restricted lake the formation of Green River sediments continued, while over the fine silt left exposed by its retreat was deposited the brightly colored clay shale of the Cathedral Bluffs tongue. After the formation of 600 to 1,200 feet of sediments composing the Cathedral Bluffs tongue Wasatch deposition came to an end by a new advance of the Green River lake, which this time encircled the east end of the mountains and united with the lake of the Uinta Basin. The much smaller thickness of the entire Green River formation at Green River, Wyo., compared with the thickness of its age equivalents—the Tipton and Cathedral Bluffs tongues and Laney shale member (possibly including representatives of the "Tower sandstone" and plant beds of Powell) at Lookout Mountain, may be partly accounted for by a gradual southeastward tilting that may have been an important factor in the second transgression of the Green River lake.

Later folding and faulting have changed the attitude of the Wasatch and Green River but have not affected their relations.

Two questions may be outlined as problems for future study. What was the mode of disappearance of the Green River lake? Are the earliest Green River beds of the Uinta Basin the age equivalents of the basal Tipton tongue or the basal part of the Laney shale member?

OIL SHALE IN THE GREEN RIVER FORMATION.

PHYSICAL PROPERTIES.

The oil shale in the Green River formation may be divided into two distinct varieties, between which there are many gradations. One variety is hard and tough. On fresh surfaces it is chocolate-brown to black and generally shows no distinct lamination. When weathered it is predominantly of a bluish-white color, and its finely laminated structure is indicated by the alternation of thin dark-gray bands with bluish-white layers. (See Pl. XXV, *B*.) The fracture is commonly subconchoidal; freshly broken faces have a vitreous or pitchy luster in the richest grades and are dull in the leaner grades. The other variety has very pronounced bedding of paper thinness and is commonly called papery shale. Its laminae, which are remarkably flexible, separate very readily. (See Pl. XXV, *C*.) Fresh samples are light to dark brown or less commonly black; weathered surfaces are light bluish gray or white. In general, the tough, massive variety yields more oil than the papery shale.

CHEMICAL PROPERTIES.

Oil shale contains little or no petroleum as such, and only a small percentage of the organic matter can be extracted with common petroleum solvents such as carbon tetrachloride carbon bisulphide, and benzene. The per centage extracted varies with the character of the shale and the solvent, but according to a table prepared by Gavin[23] the average amount extracted by six solvents from three samples of Green River shales was only 1.3 per cent of the weight of the samples.

Upon destructive distillation the organic matter in the shale yields a crude oil. According to Steuart,[24] Prof. Crum Brown gave the name "kerogen" to this organic matter of indefinite and variable chemical composition.

The economic value of the shale depends upon the character of the kerogen and the proportions of kerogen and clastic mineral matter. McKee and Goodwin[25] show that

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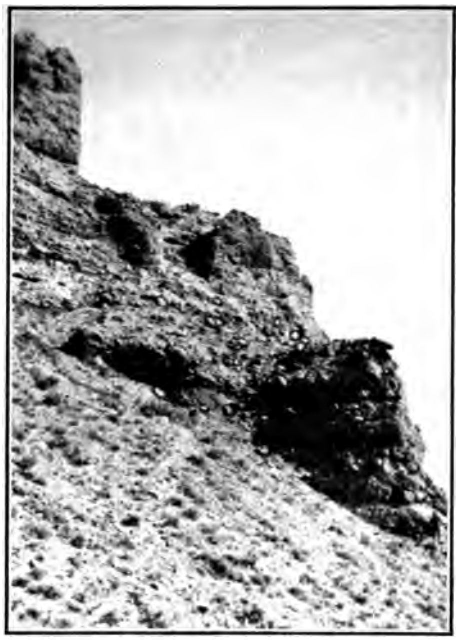
[23] Gavin, M. J., Oil shale—an historical, technical, and economic study: U. S. Bur. Mines Bull. 210, p. 28, 1922.

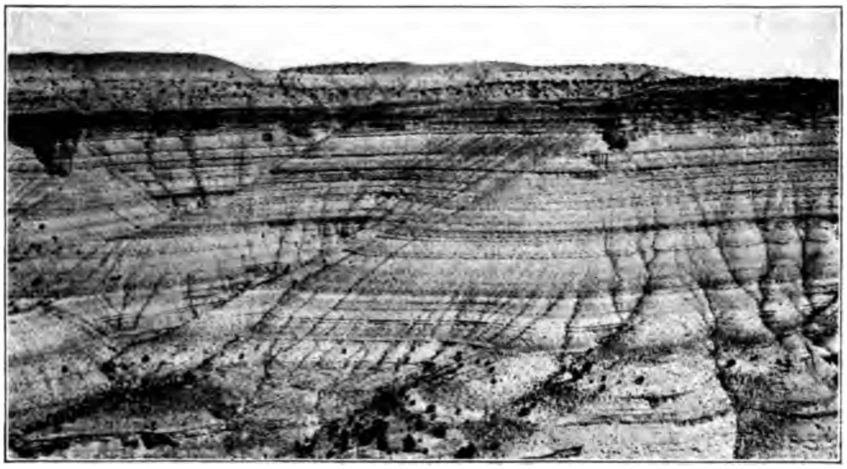
[24] Steuart, D. R., Oil shales of the Lothians, pt. 3, The chemistry of the oil shales, 2d ed., p. 159, Scotland Geol. Survey Mem., 1912.

[25] McKee, R. H., and Goodwin, R. T., A chemical examination of the organic matter in oil shales: Colorado School of Mines Quart., vol. 18, No. 1, pp. 8, 20, 1923.



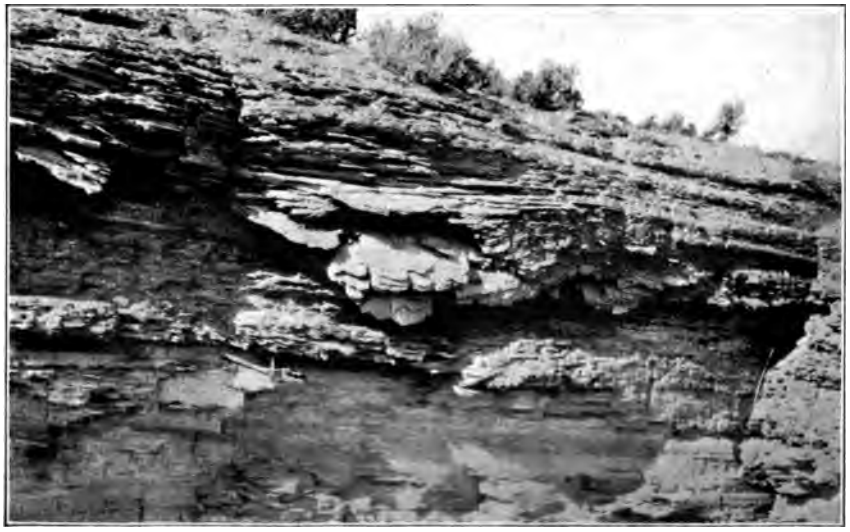
A. CONGLOMERATE IN THE LOWER PART OF THE WASATCH FORMATION AT SUGARLOAF BUTTE, SEC. 15, T. 11 N., R. 101 W., COLO.

Compare size of boulders with height of man on right side of photograph



B. OIL SHALE IN THE GREEN RIVER FORMATION, SHOWING CHARACTERISTIC THIN, REGULAR BEDDING

Photograph by D. E. Winchester



C. PAPERY OIL SHALE, SHOWING FLEXIBILITY

Photograph by D. E. Winchester

the chemical composition of the kerogen and hence of the oil distilled from it differs in different shales and even from place to place in the same formation. For example, shale oil from the Green River formation in Colorado has a mixed paraffin and asphalt base, whereas shale oil from a locality in Utah has an asphaltic base. The yield of oil is to some degree dependent upon the chemical composition of the shale, but is determined far more by the amount of kerogen present.

EFFECT OF VARYING CONDITIONS OF FORMATION

Researches of numerous careful students[26] indicate that kerogen was formed by the accumulation in fresh water of spore exines, pollen grains, the more resinous parts and somewhat macerated cuticles of larger plants, and the remains of various types of algae, particularly the more gelatinous and filmy types. The low orders of plant life, both sessile and planktonic, the drift material, and the parts of higher plants would be distributed in varying amounts through a body of fresh water according to depth, currents, wave action, source of supply of extraneous material, prevailing winds, and other factors. Where clastic material was being carried into the lake the organic content of the shale formed would be relatively smaller and the value of the shale as an oil producer would be lessened. Where the organic débris could accumulate without much influx of inorganic material the resultant shale would be very much richer in kerogen.

From this reasoning it is easily understood why the oil shale of the Green River formation near the east end of the Uinta Mountains is of very low grade. Much clastic material was carried out from the mountains and deposited in the shoreward portion of the Green River lake; the proportion of included organic material was small. Farther out in the lake, and also near shore at places where little clastic material was being supplied, the proportion of organic débris was much larger, and the shale is far richer in the oil-yielding kerogen. The variation is strikingly shown by comparison of sections of the Tipton tongue in T. 10 N., R. 100 W., Colo., and T. 12 N., R. 102 W., Wyo., with a section on Shell Creek in T. 12 N., R. 99 W., Colo.; it is indicated also by comparison of sections of the Laney shale member in T. 8 N., R. 97 W., and T. 10 N., R. 100 W., with those in T. 13 N., R. 99 W., and T. 17 N., R. 106 W. These sections, given on following pages, show a gradation northward; as the sandstones and the more limy and sandy shales disappear the percentage and richness of oil shale increase.

MEASURED SECTIONS AND TESTS.

The following sections, measured by the writers except as otherwise noted, indicate the character of the formation at different localities and present more detailed data concerning lateral changes. Results of distillation tests are given opposite the descriptions of the beds sampled. Beds described as low-grade oil shale yield less than 10 gallons to the ton.

Sections of Tipton tongue of Green River formation in Moffat County, Colo., and Sweetwater County, Wyo.

Locality 1, sec. 3, T. 10 N., R. 100 W.

	Ft.	in.
Sandstone, buff, hard, medium grained	2	6
Sandstone, brown, thin bedded, interbedded with hard gray-green shale	21	
Sandstone, gray, massive, medium grained	2	8
Shale, gray-green, platy	2	6
Sandstone, brown, medium grained	2	
Shale, greenish brown, platy to lumpy	8	
Sandstone, brown, platy, medium grained	3	
Shale, gray-green, platy	3	
Sandstone, reddish brown, medium grained, undulating bedding planes	1	6
Shale, greenish brown, sandy, platy	8	6
Sandstone, brown, very fine grained		2
Shale, gray-green, platy	2	
Sandstone, brown, very fine grained		4
Shale, gray-green, platy	4	
Sandstone, brown, very fine grained		6
Clay shale, light gray	3	
Shale, gray-green, soft, platy	6	
Sandstone, yellow-brown, thin bedded, fine grained	8	
Shale, gray-green, platy to lumpy	5	6
Shale, brown, carbonaceous, papery; trace of oil	5	6
Shale, gray to light brown, flaky	31	
Shale, chocolate-brown, carbonaceous; trace of oil	3	6

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[26] Bertrand, C. E., Les charbons humiques et les charbons des purins: Lille Univ. Trav. et Mém., vol. 6, Mém. 21, pp. 13-178, 1898; Conférences sur les charbons de terre: Soc. belge géol. Bull., vol. 11, p. 287, 1897. Davis, C. A., On the fossil algae of the petroleum-yielding shales of the Green River formation of Colorado and Utah: Nat. Acad. Sci. Proc., vol. 2, pp. 114–119, 1916; quoted in Winchester, D. E., Oil shale in northwestern Colorado and adjacent areas: U. S. Geol. Survey Bull. 641, p. 165, 1916; Oil shale of the Uinta Basin, northeastern Utah: U. S. Geol. Survey Bull. 691, pp. 46–47, 1918. Jeffrey, E. C., The nature of some supposed algal coals: Am. Acad. Arts and Sci. Proc., vol. 46, pp. 273–290, 1910. Thiessen, Reinhardt, and White, David, The origin of coal: U. S. Bur. Mines Bull. 38, pp. 199–203, 1913; Origin of certain oil shales: Econ. Geology, vol. 16, pp. 289–300, 1921. White, David, Late theories regarding the origin of oil: Geol. Soc. America Bull., vol. 28, p. 730, 1917.

	Ft.	in.
Shale, gray, flaky	3	
Sandstone, buff, cross-bedded, medium grained		10
Shale, brownish gray, papery; contains many humified plant fragments	24	
Sandstone, buff, cross-bedded; upper 3 feet platy with shaly partings	19	
Shale, dark brown, papery, brittle, carbonaceous; contains abundant humified plant fragments	56	
Wasatch formation.		
	227	

Locality 2, sec. 15, T. 12 N., R. 102 W.

	Ft.	in.
Sandstone, brown, cross-bedded, very coarse grained, locally conglomeratic, carrying red and brown quartzite boulders as much as 5 inches in diameter	15+	
Sandstone, hard, gray; irregular thin bedding	2	6
Sandstone, light gray, cross-bedded, medium to coarse grained	2	
Sandstone, gray, very hard, thin bedded, fine grained	7	6
Interval concealed, probably fine-grained lumpy sandstone	7	
Sandstone, cross-bedded, from medium grained to conglomeratic	3	
Sandstone, hard, fine grained	4	
Sandstone, brown, massive, coarse grained	2	6
Sandstone, hard, massive, fine grained	10	
Sandstone, massive, coarse grained; carries a few pebbles	2	
Shale, hard, sandy, interbedded with thin-bedded sandstone	24	
Sandstone, platy, interbedded with thin, hard, impure limestones	6	
Sandstone, hard, platy, very fine grained	4	
Sandstone, gray, soft, thin bedded to cross-bedded, medium grained	6	
Sandstone, greenish gray, hard, irregularly bedded; contains numerous soft white specks	5	
Sandstone, buff, massive, fine grained	5	6
Sandstone, greenish gray, hard, irregularly bedded; contains numerous soft white specks	11	
Sandstone, gray, cross-bedded, in part conglomeratic	9	
Sandstone, thin bedded, fine grained, interbedded with hard brown low-grade oil shale	8	6
Sandstone, basal 3 feet conglomeratic, carrying pebbles of white quartz, hard shale, red and gray chert, and limestone; remainder fine grained and irregularly thin bedded	22	
Shale, very low-grade oil shale, interbedded with numerous fine-grained platy sandstones	6	
Sandstone, brown, slightly cross-bedded; carries subangular white and pink quartzite pebbles	12	
Sandstone, blue-gray, soft, fine grained	9	
Sandstone, light gray, very coarse grained, locally cross-bedded and conglomeratic	10	
Sandstone, massive to platy, medium to fine grained	7	
Shale, sandy, platy		6
Sandstone, greenish gray, massive, sugary textured, medium grained	3	6
Shale, sandy, interbedded with thin-bedded medium-grained sandstone	4	6
Shale, hard, brown; low-grade oil shale; contains small limy concretions	5	
Sandstone, soft, medium to coarse grained and slightly cross-bedded; several 6-inch partings of hard shale	24	
Shale, laminated to lumpy; contains sandy lenses	2	3
Sandstone, reddish brown, massive, medium grained	2	6
Shale, greenish gray, hard, lumpy	2	6
Shale, hard, brown; low-grade oil shale; weathers blue-gray	3	
Sandstone, soft, medium to coarse grained	4	
Sandstone, thin bedded; interbedded with shale	5	
Sandstone, brown, medium grained		9
Shale, dark brown, laminated; low-grade oil shale		3
Sandstone, brown, coarse grained		8
Shale, hard, brown, massive; low-grade oil shale		10
Sandstone, brown, medium grained		8
Shale, chocolate-brown, hard, massive; low-grade oil shale	15	
Sandstone, red-brown, massive to thin bedded, medium to fine grained; carries leaf impressions; numerous thin partings of sandy shale	69	
Shale, sandy, gray; few thin platy sandstones	14	
Shale, brown, papery; few thin sandstones; trace of oil	11	
Concretionary zone; probably calcareous alga reef	2	
Sandstone, soft, coarse grained, cross-bedded; lower part sandy clay shale	30	
Sandstone, brown, thin bedded, fine grained	4	
Clay shale, hard, gray	9	
Sandstone, brown, soft and friable, coarse grained	18	
Clay shale, blue-gray	15	
Shale, papery; low-grade oil shale	10	
Clay shale, sandy, hard and lumpy	18	
Shale, brown, papery; low-grade oil shale	11	
Clay shale, gray; few thin sandstones	5	
Shale, chocolate-brown, papery; low-grade oil shale	17	
Sandstone, limy; full of *Goniobasis* shells		2
Gray and maroon clay shale of Wasatch formation.		
	509+	

Locality 3, secs. 27 and 28, T. 12 N., R. 99 W.

	Ft.	in.
Red and green clay shale and sandstone of the Cathedral Bluffs tongue of Wasatch formation.		
Shale, greenish gray; upper part clayey; lower part laminated low-grade oil shale	14	
Sandstone, brown, soft, thin bedded, fine grained; ripple-marked at top	4	6
Shale, greenish gray, hard, laminated	2	
Sandstone, brown, thin bedded, fine grained, interbedded with sandy shale	6	
Shale, sandy, hard	6	7
Sandstone, light gray, soft, thin bedded, interbedded with sandy shale	3	
Shale, hard and sandy, interbedded with thin fine-grained micaceous sandstones	6	2
Sandstone, brown, hard, medium grained, in part cross-bedded; abundant mica flakes		8
Sandstone and interbedded bluish-gray shale; both micaceous	8	
Zone of hard brown sandy concretions		8
Sandstone, dark gray, much cross-bedded, fine grained; distinct parting planes of mica flakes	1	
Shale, light gray; few thin micaceous sandy lenses	10	
Alga reef, calcareous	2	
Shale, hard, dark gray, papery; low-grade oil shale		6
Sandstone, buff, medium grained; numerous partings of hard sandy shale	5	6
Sandstone, buff, very thin bedded	1	4
Shale, dark gray, papery; trace of oil		5
Shale, sandy, interbedded with irregular thin sandstones	2	3
Shale, hard, sandy, interbedded with hard light-gray shale that shows trace of oil	2	
Shale, sandy, and thin sandstone	1	6
Shale, bluish gray, hard, flaky; shows trace of oil	1	6
Shale, sandy, and thin sandstones		10
Clay shale, sandy		8
Sandstone, brown, medium grained, irregularly bedded		7
Shale, gray-green, hard; trace of oil; few thin lenses of very fine sand	6	6
Sandstone, brown, soft, fine grained, massive, micaceous	2	
Shale, bluish gray, sandy	2	6
Sandstone, buff, soft, medium to coarse grained, massive, micaceous	7	
Shale, gray, hard, sandy; few thin sandstone lenses; carries a few plant fragments	9	
Sandstone, drab, soft, medium grained, micaceous	1	6
Shale, dark gray, sandy, fissile		10
Sandstone, coarse grained, thin bedded	2	
Shale, sandy, interbedded with thin sandstones; both carry abundant mica flakes	8	
Sandstone, white, very friable, coarse grained	5	
Shale, dark gray, fissile		6
Shale, dark brown, papery, tough; low-grade oil shale	9	6
Shale, sandy, and thin sandstones	2	
Sandstone, white, friable, medium grained, micaceous	6	6
Shale, dark chocolate-brown, soft	1	4
Shale, sandy, and thin soft sandstones	6	6
Sandstone, white, very soft and sugary, medium grained, micaceous	8	
Sandstone, dark reddish brown, hard, coarse grained, cross-bedded	2	6
Sandstone, buff, massive, fine grained	6	
Sandstone, dark brown, much cross-bedded, medium grained	2	
Clay shale, light brown	3	
Sandstone, buff, soft, coarse grained		6
Shale, sandy	2	
Sandstone, brown, irregularly bedded, fine grained		6
Shale, gray, soft, flaky	10	
Shale, very dark brown, hard, tough (sample IV–53; 7.5 gallons)	5	
Shale, gray to brownish, flaky	14	
Shale, dark chocolate-brown, papery; low-grade oil shale	8	
Clay shale, greenish gray, sandy	15	
Shale, dark brown to nearly black, papery; low-grade oil shale	15	
Limestone, hard, shaly		6
Shale, dark chocolate-brown, papery, somewhat carbonaceous; low-grade oil shale	18	
Clay shale	6	
Concealed, apparently sandy shale	40	
Sandstone, fine grained, thin bedded		10
Clay shale, light gray	5	
Limestone, hard, shaly		6
Shale, chocolate-brown, papery, tough; low-grade oil shale	4	8
Shale, greenish gray, sandy, flaky	4	
Shale, dark brown, papery, flexible laminae; low-grade oil shale	6	
Shale, sandy, flaky	4	
Shale, dark brown, papery; low-grade oil shale	14	
Clay shale, sandy, and thin sandstones	4	
Shale, nearly black, papery; low-grade oil shale	32	
Silicified bed of small *Goniobasis* shells		2
Sandstone, gray, medium grained, thin bedded; carries a few larger *Goniobasis* shells	4	
Wasatch formation, main body.		
	388	4

Sections of Laney shale member of Green River formation in Moffat County, Colo., and Sweetwater County, Wyo.

Locality 4, secs. 22 and 27, T. 10 N., R. 100 W.

	Ft.	in.
Sandstone, limestone, and clay shale of Bridger formation.		
Sandstone, greenish brown, medium to coarse grained, micaceous, cross-bedded	1	6
Clay shale, sandy	7	
Sandstone, greenish brown, medium grained, cross-bedded	2	2
Sandstone, greenish brown, medium grained, platy		6
Clay shale, sandy	3	6
Shell marl, largely *Goniobasis* shells		2
Clay shale, greenish gray	7	
Sandstone, dark brown, medium grained, crudely bedded	1	8
Clay shale, gray	5	
Sandstone, brown, medium grained		6
Clay shale, greenish gray, hard	9	6
Sandstone, brown, platy		10
Clay shale, gray	11	
Sandstone, hard, limy, medium grained; carries *Goniobasis* shells		3
Clay shale, sandy	5	
Sandstone, dark brown, platy	1	8
Alga reef, calcareous; some calcareous shale	2	6
Clay shale, gray	21	
Sandstone, gray, fine grained	4	
Clay shale, greenish gray	8	6
Sandstone, brown, shaly	20	
Limestone, shaly, buff	1	
Shale, brown, flaky	2	
Shale, hard, limy		8
Shale, buff, blocky	15	
Sandstone, light gray, sugary textured, medium grained, friable, massive	22	
Clay shale, sandy, pale green	7	
Sandstone, greenish gray, fine grained	2	
Clay shale, greenish gray	8	
Sandstone, gray, medium grained	1	
Clay shale, greenish gray	6	
Shale, calcareous, platy	10	
Clay shale, gray	1	
Shale, calcareous, platy	4	
Clay shale, gray	1	
Shale, calcareous, hard, platy	4	
Clay shale, gray; contains lenses of loose fine to coarse sand	21	
Limestone, buff, shaly, hard, blocky		10
Shale, yellowish brown, lumpy	1	
Limestone, brown, hard, impure, in part crystalline		5
Shale, gray to brown, platy and flaky	12	
Sandstone, light gray, friable, medium to coarse grained		11
Clay shale, greenish gray, lumpy and flaky	7	
Limestone, shaly, buff, hard, blocky	1	4
Clay shale; contains water-rounded clay balls		10
Shale, buff, hard, platy	1	7
Clay shale, light gray; contains water-rounded clay balls	1	8
Marl, shaly; irregular bedding; carries pelecypod shells		8
Alga reef, calcareous, in part silicified; carries some oolites	1	3
Clay shale, greenish gray, lumpy	8	4
Sandstone, very friable, very fine grained	21	
Shale, carbonaceous; partly humified plant remains abundant	1	8
Shale, gray, flaky and lumpy	6	2
Shale, calcareous, hard, platy	3	
Shale, gray-green, flaky	2	6
Shale, very carbonaceous		1
Clay shale, gray		6
Sandstone, massive, medium grained	1	6
Sandstone, extremely friable, very fine grained	15	
Sandstone, medium grained		1
Sandstone, soft, very fine grained	2	6
Concealed, probably clay shale	13	
Shale, gray, flaky	7	6
Limestone, shaly, hard, buff		8
Concealed, probably soft sandstone and clay shale	52	
Shale, buff, hard, platy; trace of oil	7	
Shale, brown, hard, limy		8
Clay shale	7	
Clay shale, sandy	11	
Sandstone, brown, very friable, medium grained	1	
Clay shale, greenish gray	1	4
Sandstone, gray, fine grained, banded		2
Shale, brown, carbonaceous; thin shell marls	3	5
Clay shale, sandy; lenses of soft sandstone	28	
Clay shale, gray-green	2	6
Shale, brown to black, carbonaceous		10
Concealed, probably clay shale	17	
Shiny black, soft, earthy matter; yields some oil		4
Concealed, probably clay shale	33	
Clay shale, gray-green, sandy	2	
Clay shale, gray	4	
Shale, papery; poorly exposed	6	
Shale, dark chocolate-brown, hard, tough (sample 0114–A; 10 gallons)	2	7
Shell marl, containing flat gastropods, fish vertebrae, and bone fragments		3
Shale, limy, brown; carries plant fragments; low-grade oil shale	19	6
Shale, limy, hard	1	4
Shale, chocolate-brown, hard, tough; low-grade oil shale	11	4
Clay shale, gray	1	
Shale, reddish brown, carbonaceous, very fissile; numerous plant fragments		8
Sandstone, friable, very fine-grained carbonaceous partings	1	3
Clay shale, gray	1	
Shale, brown, platy	3	6
Shell marl; *Goniobasis* and *Unio* shells	2	1

	Ft.	in.
Shale, platy; carries ostracodes		11
Shell marl; *Goniobasis* shells		1
Shale, dark gray; some plant fragments; interbedded thin shell marls	29	
Limestone, shaly, hard		6
Shale, dark-brown, hard; carries ostracodes; low-grade oil shale	14	4
Shell marl, limy; largely ostracodes		6
Shale, dark brown, hard, platy	10	
Shell marl, sandy; mostly small pelecypods		10
Shale, gray-brown; plant fragments	5	7
Clay shale, dark greenish gray, waxy	1	10
Shale, gray-brown, soft, fissile; carries ostracodes and fragments of fish teeth	13	
Shale, dark brown, papery	3	4
Limestone, blue-gray, hard, lenticular		5
Shale, hard, pale green, blocky (sample 086–A; 4 gallons)	21	
Limestone, gray, hard		4
Shale, brown, hard, locally papery; low-grade oil shale	83	
Limestone, buff, shaly, hard		5
Shale, brown, hard, platy; some beds are low-grade oil shale	43	
Sandstone, limy; carries *Goniobasis* shells		3
Shale, brown, soft, platy	7	
Shale, dark brown, carbonaceous	10	
Sandstone, limy, hard		3
Shale, dark brown, hard, platy; low-grade oil shale	87	3
Sandstone, platy		10
Shale, greenish brown, soft	16	
Limestone, sandy; carries ostracodes		1
Shale, brown, soft	2	6
Shale, yellowish brown; abundant plant fragments	13	
Shale, limy, soft, laminated		8
Shale, light brown, laminated; low-grade oil shale	5	
Shale, gray, flaky	1	
Shale, limy, yellow-brown, papery, soft	5	
Shale, light gray, hard, platy	23	6
Limestone, sandy, crystalline	1	3
Shale, light brown, soft	5	
Shale, limy, yellowish gray, soft; traces of oil	36	
Limestone, shaly, hard		4
Shale, gray, flaky	2	1
Sandstone, yellow, coarse grained	2	
Shale, limy, yellow-brown, platy	13	8
Limestone, sandy, lenticular	3	
Clay shale, gray	5	
Shale, limy, light brown, papery, soft	9	1
Limestone, buff, shaly, hard		9
Shale, limy, light yellowish brown, papery	19	
Clay shale, reddish gray	30	
Alga reef, calcareous; abundant ostracodes	1	
Limestone, oolitic, hard		3
Shale, limy, yellow brown	1	5
Limestone, gray, hard		3
Shale, limy, gray		2
Clay shale		3
Limestone, buff, shaly, hard	1	2
Clay shale, light brown		10
Shale, limy, papery, light brown, soft	9	6
Alga reef (?)		2
Sandstone, medium grained		9
Shale, light brown, laminated; trace of oil	12	10
Sandstone, medium grained		4
Limestone, gray, hard		8
Clay shale, gray	7	
Shale, limy, papery	7	
Sandstone, buff, limy, medium to coarse grained	2	6
Clay shale, gray	3	5
Shale, limy; faint bedding	1	2
Shale, dark gray, papery; trace of oil	5	
Sandstone, buff, medium to coarse grained; carries few small pebbles; locally cross-bedded	9	8
Sandstone, shaly, blocky	5	
Sandstone, buff, soft, friable, coarse grained	3	1
Sandstone, limy, buff, fine grained	1	5
Shale, greenish, limy		3
Shale, limy, light yellow-brown, laminated	22	3
Shale, limy, hard, not laminated		1
Shale, limy, light yellow, papery		4
Limestone, shaly, lenticular		2
Shale, sandy and limy; plant fragments	4	2
Clay shale, gray	1	6
Shale, light brown, papery	18	
Clay shale, dark gray	1	6
Sandstone, buff, fine grained	1	
Clay shale, gray; grades up into gray papery shale	2	9
Clay shale of Cathedral Bluffs tongue of Wasatch formation.		
	1, 199	11

Locality 5, sec. 20, T. 8 N., R. 97 W.

Top of bluff.

Sandstone; carries *Goniobasis* and *Unio* shells.

	Ft.	in.
Shale and thin sandstones	11	10
Sandstone, coarse grained	2	
Shale and thin sandstones	28	6
Shale, limy, buff; trace of oil	5	
Shale, carbonaceous and clayey	6	
Sandstone, fine grained, thin bedded	3	
Shale, carbonaceous and clayey	21	8
Shale, limy, hard	2	3
Shale, gray, carbonaceous and clayey	41	6
Shale, greenish; plant fragments		4
Limestone, shaly, gray	1	6
Clay shale, gray	2	
Shale, limy, hard	3	
Shale, light brown, platy; low-grade oil shale	23	7
Clay shale, sandy; contains thin beds of coal	16	6
Sandstone, brown, coarse grained	5	
Shale, black, carbonaceous		3
Shale, limy, soft	1	4
Shale, brown; some plant fragments		8

	Ft.	in.
Clay shale, gray and pink	12	4
Sandstone, gray, hard, platy, thin bedded	4	7
Shale, limy, buff, platy	41	
Shale, limy, buff, hard; trace of oil	6	
Shale, gray; lower 48 feet limy; upper part low-grade oil shale	61	6
Shale, brown to black, carbonaceous		6
Shale, sandy, gray	4	5
Sandstone, fine to medium grained	9	6
Shale, sandy, hard	2	
Shale, limy, hard, buff	3	7
Sandstone, gray, fine grained	4	6
Shale, sandy, fissile	1	8
Shale, carbonaceous		1
Shale, limy	3	6
Shale, gray, hard; low-grade oil shale	20	
Shale, gray, soft; trace of oil	52	6
Shale, brown, hard; low-grade oil shale	79	10
Shale, limy, hard, barren		3
Shale, brown, laminated; low-grade oil shale	8	8
Shale, very limy, brown; low-grade oil shale	1	6
Shale, limy, hard, barren		8
Shale, brown, laminated, hard (sample II-86-88; 9.5 gallons)	3	
Shale, limy, hard (not sampled)		6
Shale, brown, laminated, hard	15	2
Shale, limy, hard, barren		10
Shale, gray to brown, hard, laminated; low-grade oil shale	2	10
Limestone, shaly, buff, hard		5
Shale, gray to brown, hard, laminated; low-grade oil shale		8
Limestone, shaly, buff, hard		3
Shale, brown; weathers papery; low-grade oil shale	9	2
Shale, black, carbonaceous		2
Shell marl, silicified	1	2
Sandstone, gray, hard, fine grained	1	2
Shale, platy, silicified		8
Shale, brown, fissile; low-grade oil shale	1	3
Shale, silicified		7
Shale, gray, fissile		2
Shale, limy, hard		6
Shale, dark brown, hard, tough; low-grade oil shale	25	4
Shale, silicified	1	2
Shale, gray to brown; low-grade oil shale		11
Shale, limy, hard		5
Shale, dark brown, hard, platy; low-grade oil shale	13	10
Limestone, silicified		5
Shale, brown to buff; trace of oil	14	
Clay shale, greenish	2	2
Shale, gray, soft	8	
Shale, dark gray, hard; low-grade oil shale	8	3
Shale, gray, hard, blocky; trace of oil; interbedded with few thin hard shaly limestones	4	4
Shale, gray, papery; limy shale interbedded	5	
Clay shale, greenish, waxy	1	2
Shale, limy, yellow, hard		9
Shale, light brown, laminated	8	
Limestone, shaly, hard, buff		4
Shale, gray to buff, hard, platy to papery; some beds of low-grade oil shale	83	6
Shale, dark gray; fragments of shells; will probably yield some oil		2
Shale, black, soft	8	1
Clay shale (?), soft, yellow, waxy		2
Shale, gray, soft	4	
Limestone, shaly, gray, hard		1
Shale, gray, sandy and limy, flaky	1	8
Sandstone and sandy shale, thin bedded	33	6
Shale, limy	27	
Sandstone, thick bedded to massive	38	4
Shale, limy, platy	14	2
Sandstone, irregularly thin bedded to massive	6	8
Shale, gray, papery	4	4
Sandstone (base of Green River)	11	
	814	3

Locality 6, sec. 3, T. 13 N., R. 99 W.

[According to Schultz.[27]]

	Ft.	in.
Top of bluff.		
Sandstone, coarse grained, not massive	50	
Sandstone, containing fossil shells		4
Sandstone, coarse grained, thin bedded	10	
Covered, probably sandy shale	35	
Sandstone, coarse	8	
Covered, mostly shale	30	
Shale, papery, drab, lean	5	
Shale, thin, barren, and sandstone	72	
Shale, drab, thin, lean	3	
Shale, thin, drab, barren	20	
Shale, thin, lean	30	
Sandstone, concretionary	1	
Shale, thin, lean	14	
Oolite and chert.		
Shale, thin bedded, lean	14	6
Shale, thin bedded; weathers blue; rich (sample 1; 30 gallons.)	2	
Shale, gray, sandy (not included in sample)	1	7
Sandstone, yellow (not included in sample)	1	
Shale, thin bedded; weathers blue; rich	3	
Shale, yellow, sandy	28	
Shale, papery, lean	40	
Shale, drab, fissile	10	
Sandstone, concretionary	1	
Shale, drab, papery (over 15 gallons)	13	
Oolite		6
Shale, drab, papery (over 15 gallons)	10	
Sandstone, oolitic		4
Shale, drab, fissile	12	6
Sandstone, micaceous	1	
Sandstone, yellowish	3	
Shale, drab; thin sandstone lenses	26	
Sandstone, shaly, yellowish	1	

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[27] Schultz, A. R., Oil possibilities in and around Baxter Basin, in the Rock Springs uplift, Sweetwater County, Wyo.: U. S. Geol. Survey Bull. 702, p. 54, 1920.

	Ft.	in.
Shale, drab, papery, barren	5	
Sandstone, shaly, yellowish	1	6
Shale, greenish drab	37	
Cathedral Bluffs tongue of Wasatch formation.		
	489	4

Locality 7, secs. 17 and 19, T. 17 N., R. 106 W.

[According to Winchester.[28]]

		Ft.	in.
Sandstone, massive, brown, coarse ("Tower sandstone" of Powell)		125	
Sandstone, thin bedded		35	
Shale, papery, gray		25	
Sandstone, shaly, gray		32	
Shale, sandy, lean		65	
Shale, hard; contains fish remains (sample 120; 14 gallons)		5	
Shale, lean		20	
Shale, thin, with lenses of very rich waxy shale		55	
Shale, hard		15	
Shale, hard (sample 119; 12 gallons)		5	
Shale, hard, lean		12	
Shale, gray, sandy		20	
Shale, hard, rich (more than 15 gallons)		1	4
Shale, gray, sandy, thin sandstones, and a few 1 to 3 inch beds of rich shale		90	
Shale, hard, thin, medium rich		1	6
Shale, barren		15	
Shale, medium, with large gypsum crystals		1	6
Shale, thin, barren		80	
Shale, medium, with gypsum crystals			8
Shale, gray, sandy		26	
Shale, medium, with gypsum crystals		1	6
Shale, hard, rich (over 15 gallons)			10
Sandstone, thin, gray		8	
Shale, hard, rich (over 15 gallons)			10
Shale, gray, sandy		17	
Shale, hard, rich (over 15 gallons)			2
Shale, thin, gray, sandy		9	2
Shale, hard, rich (over 15 gallons)			10
Shale, sandy		118	
Sandstone, gray		4	
Shale, sandy, greenish		6	
Sandstone, gray, thin bedded		1	
Shale, sandy, green		27	
Shale, sandy, thin bedded, gray		21	
Sandstone and shale, green, in beds 2 feet thick; sandstone concretionary		58	
Shale, sandy, gray, slope		97	
Sandstone, massive, cross-bedded, forming ledge and capping hill		5	
Shale, forming slope		43	
Sandstone, rather massive, forming ledge		10	
Shale, soft, thin, platy, barren		30	
Shale, medium hard, rather thin, very lean		4	11
Shale, medium hard (sample 116; 4 gallons)		4	10
Shale, sandy, lean to barren		70	
Shale, medium hard, very lean		10	
Shale, lean		4	6
Sandstone, brown, persistent			8
Shale, lean		3	6
Shale, hard to medium hard (sample 115; 9 gallons)		4	6
Shale, lean to barren		75±	
Shaly sandstone, barren		15	
Shale, sandy, forming slope, lean		47	
Shale, hard (sample 114, lower 4½ feet; 11 gallons)		5	6
Shale, hard (sample 113; 10 gallons)		5	3
Shale, hard	(sample 112; 9 gallons)	1	4
Sandstone			3
Shale, fairly soft, thin bedded		2	9
Shale, hard		1	
Shale, hard, rich (sample 111; 19 gallons)		5	4
Shale, hard, rich (sample 110; 19 gallons)		6	3
Shale, soft	(sample 109; 11 gallons)		7
Shale, hard, rich		2	5
Shale, soft			6
Shale, hard, rich		2	3
		1, 360 ±	

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[28] Winchester, D. E., Oil shale of the Rocky Mountain region: U. S. Geol. Survey Bull. 729, pp. 124, 125, 1923.

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Professional Paper 132—G

DISCOVERY OF A BALKAN FRESH-WATER FAUNA IN THE IDAHO FORMATION OF SNAKE RIVER VALLEY, IDAHO

BY

W. H. DALL

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Shorter contributions to general geology, 1923–1924

(Pages 109–115)

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ILLUSTRATION.

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PLATE XXVI. Fossils of the Idaho formation 112

DISCOVERY OF A BALKAN FRESH-WATER FAUNA IN THE IDAHO FORMATION OF SNAKE RIVER VALLEY, IDAHO.

By W. H. Dall.

In 1866 Gabb [1] described *Melania taylori* and *Lithasia antiqua* "from a fresh-water deposit on Snake River, Idaho Territory, on the road from Fort Boise to the Owyhee mining country. Collected by Mr. A. Taylor." He states that a small bivalve, perhaps a *Sphaerium*, was associated with them.

In 1870 Meek[2] described two species of *Sphaerium*, one from Fossil Hill, Nev. (included by King in his Truckee group), and one from Castle Creek, Idaho. Both these species occur in the Idaho material, and the presumption is strong that the two deposits are of the same age. In 1877 Meek[3] redescribed and figured them, considering their age as probably Miocene.

In 1882 C. A. White [4] added another species, *Latia dalli*, from the Idaho deposits and referred the formation on King's authority to the Miocene. King [5] does refer his Truckee group to the Miocene, but on another page [6] he specifically refers the Idaho lake beds to the Pliocene. In this he is followed by Cope,[7] who proposes for these beds an "Idaho group," which he regards as of middle or lower Pliocene age. As the molluscan fauna of the Truckee formation is practically the same as that of the Idaho formation, this conclusion would carry at least part of the Truckee into the Pliocene column.

In 1898 Lindgren [8] gave the name Payette formation to plant-bearing lake deposits in the lower part of the Snake River valley, which he referred to the Miocene on the evidence of the flora as determined by Knowlton, and stated that "this formation is probably not the same as Cope's Idaho formation, to which a Pliocene age was assigned." A footnote on the same page records the later conclusion that the Payette and Idaho formations represent two successive stages of the same lake and that it is not always easy to separate the two formations.

In the latest publication on the Payette formation R. W. Chaney,[9] who has revised and added to the flora, concludes that the formation is Miocene, and states that this determination from the flora is also supported by the evidence of vertebrate fossils obtained by Buwalda.

In a discussion of Pliocene mammalian faunas from the Pacific coast and Great Basin provinces John C. Merriam [10] says:

> The Idaho formation is not as yet satisfactorily separated from the Payette Eocene or Miocene and from a Miocene or Pliocene stage which may intervene between the Payette and the Idaho. It is, however, quite certain that there exists over a large area of southwestern Idaho a formation several hundred feet thick which may show evidence of deformation and which contains a fauna of a stage representing either the latest Pliocene or the earliest Pleistocene.

The fresh-water molluscan fauna which is the subject of this paper apparently comes from the same beds that yielded the Pliocene or Pleistocene vertebrate fauna referred to by Merriam. The fresh-water deposits in Serbia, Hungary, and other parts of southeastern Europe are sometimes referred to in the literature as Miocene but are generally called Neogene without attempting to discriminate between Miocene and Pliocene ages. They are characterized by very numerous species of the genera *Limnocardium*, *Congeria*, *Melanopsis*, *Neritina*, and operculate forms related to *Bythinia*, none of which occur in North American lake beds so far as now known. In addition they contain a number of genera strikingly different from any now living in the fresh waters of the globe, such as *Valenciennesia*, *Velutinopsis*, *Papyrotheca*, *Orygoceras*, and *Baglivia*. There are also a few of the smaller forms like *Caspia* which are found living or represented by close analogues in the Caspian Sea and Lake Baikal, both of which, it may be noted, are "relicten Seen."

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[1] Gabb, W. M., Paleontology of California, vol. 2, p. 13, pl. 2, figs. 21-22, 1866.

[2] Meek, F. B., Acad. Nat. Sci. Philadelphia Proc. for 1870, pp. 56-57, 1870.

[3] Meek, F. B., U. S. Expl. 40th Par. Rept., vol. 4, pt. 1, p. 183, pl. 16, figs. 17-20, 1877.

[4] White, C. A., U. S. Nat. Mus. Proc., vol. 5, p. 100, pl. 5, figs. 17-20, 1882.

[5] King, Clarence, U. S. Geol. Expl. 40th Par. Rept., vol. 1, p. 412, 1878.

[6] Idem, p. 440.

[7] Acad. Nat. Sci. Philadelphia Proc. for 1883, pp. 153-166, 1883.

[8] U. S. Geol. Survey Eighteenth Ann. Rept., pt. 3, p. 632, 1898

[9] Notes on the flora of the Payette formation: Am. Jour. Sci., 5th ser., vol. 4, pp. 214-222, 1922.

[10] California Univ. Dept. Geology Bull., vol. 10, p. 432, 1917.

The chief interest of the present paper lies in the discovery of some of these anomalous fresh-water genera in American lake beds of the Idaho formation, together with one or two curious forms not represented in Europe.

In 1909 A. A. Hinkley obtained from the wash of the Panuco River system, in the Mexican State of San Luis Potosi, some amnicoline shells which were recognized by H. A. Pilsbry as closely related to some of the forms from the Serbian lake beds, described by Brusina, and which were described by Pilsbry[11] under the names *Emmericiella* and *Pterides*. It is not certain that these bleached specimens represent living species, as they might have been washed out of unconsolidated marl.

The genus *Tryonia* Stimpson, 1865, from the Colorado Desert fossil fauna, is undoubtedly an American type, but conchologically many of the shells named *Prososthenia* by Neumayr in 1869, from the Balkan lake beds, are almost identical with our *Tryonia*, which ranges from supposed Miocene deposits in Guatemala to the recent fauna of certain springs in California, to which it has retreated from the growing salinity of the former Lake Bonneville, now desert.

The United States Geological Survey recently received from Prof. F. A. Thomson, of the Idaho School of Mines, a piece of rock collected by W. H. Campbell from Castle Creek, Owyhee County, Idaho, and containing numerous fresh-water shells.

A fine iconography of the Mollusca of the Balkan lake beds was published by the late Spiridion Brusina[12] in 1902, and an examination of the Idaho material showed at once the presence of some of the remarkable European forms hitherto unknown in the Western Hemisphere.

The matrix consists of rather large rounded sand grains firmly cemented together and containing numerous fresh-water shells. The matrix is so flinty and the minute shells so extremely fragile that several specimens crumbled during the attempt to extricate them, and subsequent work was confined to the recording of such descriptive data as could be derived from an inspection of the more or less embedded individuals on the surface of the rock specimen.

The interest excited by this discovery led to an examination of all the material in the collection which had been obtained from this district, some of which had been tentatively reported on many years ago. Specimens were found which had been collected during the Fortieth Parallel Survey, by I. C. Russell, G. R. Mansfield, G. H. Eldridge and others, most of which had a matrix of fine-grained sandstone or shale. Curiously enough, none of them showed any trace of the Balkan species, except one found near Glenn's Ferry, in the Snake River canyon, which contained a fragment now recognizable as part of a species of *Orygoceras*. Though fossils were abundant, they represented only a few species which had been described by Gabb, Meek, and White in the publications above referred to. Taken altogether the number of lots is small, and their fossil content meager.

The condition of the matrix in the Thomson specimen is such that, while the generic relations of most of the fossils are determinable, for many of them it is not practicable to obtain sufficient data for specific determination, and some of the shells show evidence of having been worn or eroded before fossilization.

In enumerating the fossils of the Balkan type I have retained the nomenclature of Brusina, leaving questions of synonymy, if any, to be determined later.

PELECYPODA.

Genus SPHAERIUM Scopoli.

Sphaerium rugosum Meek.

Sphaerium rugosum Meek, Acad. Nat. Sci. Philadelphia Proc. for 1870, p. 56, 1870; U. S. Geol. Expl. 40th Par. Rept., vol. 4, pt. 1, p. 182, pl. 16, figs. 1, 1a, 1877.

White, C. A., U. S. Nat. Mus. Proc., vol. 5, p. 100, pl. 5, figs. 14–15, 1882; U. S. Geol. Survey Third Ann. Rept., p. 234, pl. 32, figs. 12–13, 1883.

Fossil Hill, Kawsoh Mountains, Nev.; Meek. Castle Creek, Owyhee County, Idaho; W. H. Campbell.

These specimens are identical with Meek's type. His locality was later included in the State of Idaho.

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[11] The Nautilus, vol. 23, pp. 45–49, 1909.

[12] Iconographia molluscorum fossilium in Tellure tertiaria Hungariae, Croatiae, Slavoniae, Dalmatiae, Bosniae, Hertzegovinae, Serbiae, et Bulgariae inventorum, pp. x, 30, pl. 30, Agram, 1902.

Sphaerium meeki Dall, n. sp.

Plate XXVI, Figure 8.

Castle Creek, Idaho; Campbell.

A single valve of a small *Sphaerium* was obtained which is distinctly different from the preceding species. It is roundly rectangular in outline, the beak nearer the anterior end, low and smooth; sculpture of about ten cordlike concentric ridges with subequal interspaces, more crowded and less elevated toward the base; the valve thin, compressed, the anterior end somewhat more bluntly rounded than the other; the hinge and interior obscured by matrix. Longitude 5 millimeters; altitude 3 millimeters. U. S. Nat. Mus. catalog No. 333521.

Sphaerium idahoense Meek.

Sphaerium idahoense Meek, Acad. Nat. Sci. Philadelphia Proc. for 1870, p. 57, 1870; U. S. Geol. Expl. 40th Par. Rept., vol. 4, pt. 1, p. 183, pl. 16, figs. 1, 1a, 1877.

White, C. A., U. S. Nat. Mus. Proc., vol. 5, p. 100, pl. 5, figs. 12-13, 1882; U. S. Geol. Survey Third Ann. Rept., p. 34, pl. 32, figs. 14-15, 1883.

Castle Creek, Idaho, Meek; also Campbell.

This species is a much heavier shell than any of the recent Sphaeria and according to Meek has a sinuation of the palleal line like the old world Cyrenas, while the recent American species have a simple entire palleal line. I have not been able to detect any sinuation in the specimens I have examined. Meek was uncertain to which genus to refer it but tentatively placed it in *Sphaerium*. The shape is more like *Cyrena*.

GASTROPODA.

Family LYMNAEIDAE.

Genus LYMNAEA Lamarck.

Lymnaea? sp.

A shell having much the outline of *Lymnaea vetusta* Meek, with a distinctly truncate pillar and a gyrate internal axis, was obtained by G. R. Mansfield from the Salt Lake formation in the N. ½ sec. 24, T. 10 S., R. 43 E., in Idaho. It is perhaps not a *Lymnaea*, but the form is so obscured by a hard shaly matrix that a definite determination of the genus is not practicable.

Family PLANORBIDAE.

Genus PLANORBIS Müller.

Planorbis? sp.

Fragments and partial impressions of shells which may be planorboid are not rare in the material at hand, but they are not sufficiently well preserved to distinguish them from small or young specimens of *Vorticifex*.

Subfamily POMPHOLIGINAE.

Genus VORTICIFEX Meek.

Vortifex Meek, Acad. Nat. Sci. Philadelphia Proc. for 1870, p. 59; type *Carinifex* (***Vortifex***) ***tryoni*** Meek, loc. cit., sole example.

Vorticifex tryoni Meek.

Carinifex (*Vortifex*) *tryoni* Meek, Acad. Nat. Sci. Philadelphia Proc. for 1870, p. 59, 1870.

Carinifex (*Vorticifex*) *tryoni* Meek, U. S. Geol. Expl. 40th Par. Rept., vol. 4, pt. 1, p. 188, pl. 17, figs. 10, 10a-10c, 1877.

White, C. A., U. S. Nat. Mus. Proc., vol. 5, p. 100, pl. 5, figs. 8-9, 1882.

Fossil Hill.

Vortifex, according to Meek, 1877, was a typographic error. It is extremely doubtful whether this form and its Pleistocene relatives have any distinctive characters separating them from *Pompholyx* Lea (not Gosse), *Pompholopsis* Call, and *Parapholyx* Hanna.

Generally the large *Carinifex binneyi* has been figured as typical of *Vorticifex*, but Meek did not originally place it in this group, which consisted only of the present species and its varieties.

An examination of the large series of recent *Pompholyx* in the National Museum reveals a great amount of variation. Nearly every lot of the recent shells contains a few more or less distinctly umbilicate specimens, though the typical form is imperforate. The Pleistocene specimens are smaller, more solid, and generally umbilicate; the Pliocene ones more distinctly so. One must recognize in this material, as with many other fresh-water gastropods, either one form with a multiplicity of varieties merging into one another, or a lot of species that can not be diagnostically separated.

Genus MEGASYSTROPHA Lea.

Megasystropha Lea, Acad. Nat. Sci. Philadelphia Proc., 2d ser., vol. 8, p. 5, January, 1864. Type, *Planorbis newberryi* Lea, 1858.

Carinifex Binney, W. G., Smithsonian Misc. Coll. No. 143, pt. 2, p. 74, September, 1865. Type, *Planorbis newberryi* Lea, Acad. Nat. Sci. Philadelphia Proc. for 1858, p. 41, 1858.

December 9, 1863, while Mr. W. G. Binney was engaged in preparing an account of the land and fresh-water shells of the United States for the Smithsonian Institution, desiring the opinion and criticism of his colleagues, he induced Professor Henry to send out a set of proof sheets (not for sale) to a few persons who were interested in the study of mollusks. In the preface to these sheets Professor Henry, while explaining their purpose, remarks: "As a mere proof which will undoubtedly receive many corrections, these pages should not be quoted as authority or referred to as a published work."

These proofs were in page form printed on one side of the paper, and on the eleventh sheet occurs the absolutely nude name "*Carinifex newberryi* Lea." There was, prior to the issue of this proof, an *Ancylus newberryi* Lea, 1858, a *Planorbis newberryi* Lea, 1858, a *Melania newberryi* Lea, 1860, and a *Goniobasis newberryi* Lea, 1863, but no *Carinifex newberryi*, nor was there in the proof sheets referred to any indication which of the above-named species might be intended by Binney's *Carinifex newberryi*.

The first publication of the genus *Carinifex* occurred, as indicated in the preceding synonymy, in September, 1865. But Lea's name had been fully diagnosed and published in January or February, 1864. It would seem that, under the circumstances and according to the rules, *Megasystropha* should be accepted.

Megasystropha binneyi Meek.

Carinifex binneyi Meek, Acad. Nat. Sci. Philadelphia Proc. for 1870, p. 59, 1870.

Carinifex (*Vorticifex*) *binneyi* Meek, U. S. Geol. Expl. 40th Par. Rept., vol. 4, p. 187, pl. 17, figs. 11, 11a, 1877.

Fossil Hill.

Meek, in 1877, attempted to make this species the type of *Vorticifex*, but as it was not included in the subgenus as originally proposed, this, under the rules, can not be accepted.

This species differs from the typical *Megasystropha* in having the spire deeply sunken instead of elevated, and the peripheral edges rounded instead of carinate. This gives it a much more planorboid aspect. It may typify a section *Paradines*. *Pompholopsis* Call, 1888, typified by *P. whitei* Call, may form another section for fossil forms more turbinate, solid, and umbilicate than the recent type. The relations of *Choanomphalus* Gerstfeldt, a recent form of Lake Baikal, to the present group are in need of elucidation.

Subfamily PAYETTINAE.

Genus PAYETTIA Dall, n. gen.

Payettia dalli (White).

Latia dalli White, U. S. Nat. Mus. Proc., vol. 5, p. 100, pl. 5, figs. 17–20, 1882; U. S. Geol. Survey Third Ann. Rept., p. 45, pl. 32, figs. 37–40, 1883.

Fifty miles below Salmon Falls, Snake River; White. Castle Creek, Owyhee County, Idaho; Campbell. Also various other localities in the Idaho formation.

This is one of the relatively few species which appear to be widely distributed in the lake-bed deposits.

Though White recognized the differences between the Australasian and Japanese genus *Latia* and the present fossil, he nevertheless tentatively referred the fossil to the same genus.

Latia is a small fresh-water shell, with a short deck from which a prominent spurlike process projects. *Payettia*, on the other hand, has a simple deck like a *Crepidula*, but relatively smaller, and the shell grows to many times the size of *Latia* and is thin and undulated. The geographic distance between the two faunas alone would suggest the probable generic distinctness of the two forms, which is definitely confirmed by the shell characters. *Payettia*, however, is not represented in the Balkan fossil fauna.

Family ANCYLIDAE.

Genus ANCYLUS O. F. Müller.

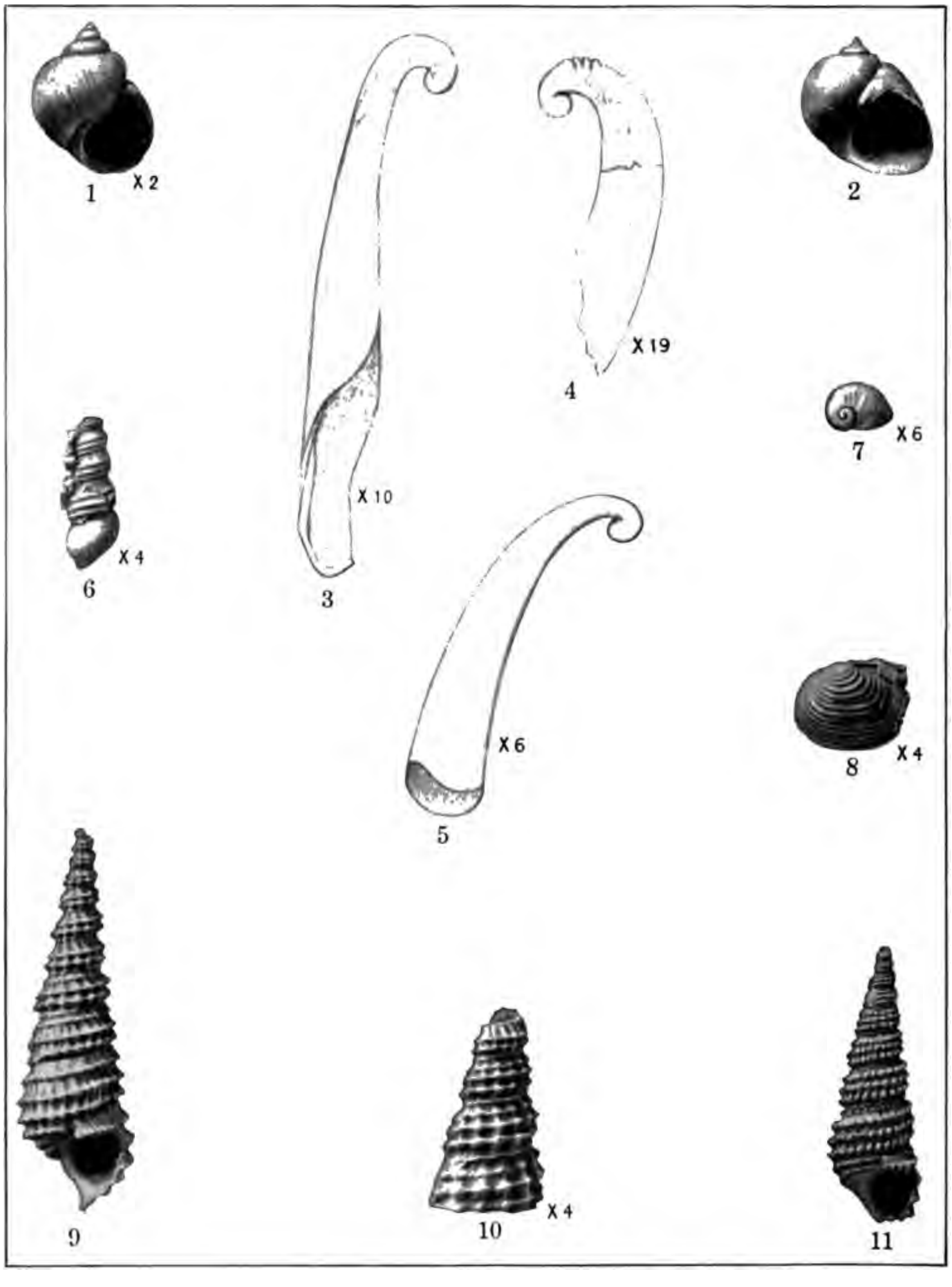
Ancylus undulatus Meek.

Ancylus undulatus Meek, Acad. Nat. Sci. Philadelphia Proc. for 1870, p. 57, 1870: U. S. Geol. Expl. 40th Par. Rept., vol. 4, p. 186, pl. 17, figs. 12 a–b, 1882.

White, U. S. Geol. Survey Third Ann. Rept., p. 45, pl. 32, figs. 10, 10a, 1883.

Fossil Hill.

I have not seen this species.



FOSSILS OF THE IDAHO FORMATION.

1. *Lithoglyphus campbelli* Dall.
2. *Lithoglyphus antiquus* (Gabb).
3. *Orygoceras* (*Ibicicornu*) *idahoense* Dall.
4. *Orygoceras* (*Ibicicornu*) *crenulatum* Dall.
5. *Orygoceras* (*Ibicicornu*) *arcuatum* Dall.
6. Apical whorls of *Goniobasis taylori* (Gabb).
7. *Aphanotylus whitei* Dall.
8. *Sphaerium meeki* Dall.
9. *Goniobasis taylori* (Gabb).
10. *Goniobasis taylori* (Gabb), upper part of spire.
11. *Goniobasis* (*taylori* var.?) *calkinsi* Dall.

Family ORYGOCERATIDAE.

Genus ORYGOCERAS Brusina.

Orygoceras Brusina, Beitr. Paläontologie Oesterr.-Ungarns u. des Orients, vol. 2, p. 33, Wien, 1882; Iconographia molluscorum fossilium, p. viii, pl. 2, 1882.

Fischer, Manuel de conchyliologie, p. 735, fig. 504, 1885.

This extraordinary genus, resembling *Parastrophia* of the Caecidae among marine mollusks, but probably not operculate, is divisible into several quite distinct sections. No type was selected by the author, and therefore I select the example figured by Fischer, *O. cornucopiae* Brusina, as representing the typical section.

I. Section *Orygoceras* (strict sense). Shell tubular, with a small spiral apex, straight or slightly arcuate, cylindrical, gradually expanding, sculptured with regularly spaced transverse lamellae. Type *O. cornucopiae* Brusina.

II. Section *Ibicicornu*. Shell longitudinally subcarinate, with a dextral twist. Type *O. fistula* Brusina.

III. Section *Bovillina*. Shell smooth, with circular section, more or less arcuate. Type *O. corniculum* Brusina.

IV. Section *Incilicornu*. Shell nearly straight, longitudinally finely striate, slightly twisted near the apex. Type *O. leptonema* Brusina.

Members of sections I and IV have not yet been detected in America.

Orygoceras (Ibicicornu) idahoense Dall, n. sp.

Plate XXVI, Figure 3.

Castle Creek, Owyhee County, Idaho; Campbell.

Shell minute, nearly straight, except the spiral nucleus of about one whorl, beyond which the whorl describes a semicircular arc equal to about half a revolution, beyond which the slowly enlarging tube becomes nearly straight; on the basal side of the spire a low rounded carina is initiated, which continues as far as the anterior end of the tube, making about half a revolution around it, the surface behind it appearing slightly flattened, the total aspect indicating a twist of the tube; the transverse section of the otherwise smooth tube, except for the slight indentation at the end of the carina, being circular. Longitude about 7 millimeters; diameter 1.5 millimeters. U. S. Nat. Mus. catalog No. 333522.

This resembles *O. fistula* Brusina but is longer and has the apex arched loosely, whereas in the Balkan species the apical part joins the nearly straight tube without an open arch.

Orygoceras (Ibicicornu) crenulatum Dall, n. sp.

Plate XXVI, Figure 4.

The apical portion and part of the succeeding tubular part of another species was found with the shell described above. The spiral apex is somewhat less involved, and the arch narrower; above the arch the periphery of the tube has four or five prominent transverse crenulations; the succeeding portion of the tube, in addition to the chief carina, has the beginning of a feebler second carina above it and near the periphery of the tube. The remainder of the shell was buried in the matrix and inaccessible. The length of the visible portion is about 3 millimeters. U. S. Nat. Mus. catalog No. 333523.

Orygoceras (Ibicicornu) arcuatum Dall, n. sp.

Plate XXVI, Figure 5.

Castle Creek, with the preceding species.

Shell minute, smooth, arcuate, rather rapidly enlarging, the spiral part reduced to a minute bulb at the apex of the tube, the carina feeble but evident and becoming obsolete anteriorly; the twist in the tube well marked. Longitude 7.5 millimeters; diameter 1.7 millimeters. U. S. Nat. Mus. catalog No. 333524.

This is nearest to *O. cnemopsis* Brusina but is at least one-third longer, is less angular, and increases more rapidly in diameter.

Orygoceras (Bovillina) tuba Dall, n. sp.

Castle Creek, with the preceding species.

Shell small, smooth, ecarinate, the apex loosely coiled, forming hardly more than one-half of a revolution; the cross section of the earlier part of the tube is slightly compressed laterally but later becomes circular; the aperture has its sides slightly arcuately produced, the edges receding between them; there is no trace of a carina, but a slight twist is perceptible. Longitude 8 millimeters; diameter of aperture 2 millimeters. U. S. Nat. Mus. catalog No. 333525.

This is nearest to *O. corniculum* Brusina, which is only 3 millimeters long and has a less even arcuation and a closely coiled nucleus, with no arch to speak of. A fragment of *O. tuba* on another piece of rock, without apex or aperture, is 7 millimeters long and indicates that a perfectly adult specimen might reach a length of over 10 millimeters.

Family MELANIIDAE.

Genus GONIOBASIS Lea.

The forms described below are devoid of the anterior angularity of the margin of the aperture which suggested the generic name, but in a large number of the recent species now referred to the genus this feature is also absent, so it seems more probable that the fossil forms are related to the American genus than to the exotic typical *Melania*, which is not represented in the recent American fauna.

Goniobasis taylori (Gabb).

Plate XXVI, Figures 6, 9, 10.

Melania taylori Gabb, Paleontology of California, vol. 2, p. 13, pl. 2, fig. 21, 1865.
White, U. S. Nat. Mus. Proc., vol. 5, p. 100, pl. 5, fig. 3, 1882; U. S. Geol. Survey Third Ann. Rept., pt. 3, p. 55, fig. 3, 1883.
Goniobasis tayloriana Pilsbry, Nautilus, vol. 13, p. 66, 1899.

Castle Creek, Owyhee County, Idaho; A. Taylor, W. H. Campbell. Near Glenn's Ferry; I. C. Russell.

The typical *G. taylori* has sharp sculpture with the arcuate axial ridges sharp and prominent, usually with wider interspaces; on the last whorl there are six, on the preceding two whorls three, and on the earlier whorls two sharp spirals. The spire is elongate, tapering to an acute apex, and comprises ten or twelve whorls. The earlier ones are often eroded and appear nearly or quite smooth.

A variety of this species, more abundant at Castle Creek than the typical form, has the axial sculpture inconspicuous, the nodulation at the intersections rounded, and behind the last whorl all the whorls of the spire have three similar spirals. This may take the name *G. taylori* var. *calkinsi* (Pl. XXVI, fig. 11). This was also collected in the Snake River canyon 1 mile east of Slick Bridge, on the south side of the river, by F. C. Calkins. U. S. Nat. Mus. catalog No. 333526.

Genus MICROMELANIA Brusina.

Micromelania Brusina, Fossile Binnen-Mollusken aus Dalmatien, Kroatien und Slavonien, p. 133, Agram, 1874. Type, *M. cerithiopsis* Brusina.

These are small subcylindric shells with numerous whorls and well-impressed suture. The aperture is simple. The original type is a sculptured shell, but of ten species figured in his Atlas, Brusina shows only one with pronounced sculpture. In the matrix of the material from Castle Creek there are a number of internal casts and fragments which might be referred almost indifferently to this genus or to *Pterides*, but in no specimen is the aperture preserved.

Family HYDROBIIDAE.

Genus CASPIA Dybowski.

Caspia Dybowski, Mal. Blätter, neue Folge, Band 10, p. 34, 1887. First species *C. baeri* Dybowski, p. 36, pl. 3, figs. 4 a–b, which may be taken as the type.

This small operculate is found living in the Caspian Sea, and numerous species occur in the Balkan fresh-water deposits. Internal casts which might belong to a species like that (unnamed) which is figured in Brusina's Atlas, Plate XI, Figures 14–15, occur in the Castle Creek material but can not be positively identified.

Genus NEMATURELLA Sandberger.

Nematurella Sandberger, Conchylien der Vorwelt, p. 575, 1874. Sole example, *N. flexilabris* Sandberger, p. 575, pl. 20, figs. 24, 24c.
Brusina, Atlas, p. viii, pls. 9, 11, 29, 1902.

Two worn specimens from the Castle Creek material are very close to the unnamed species figured in Brusina's Atlas, Plate XI, Figure 26, but are hardly well enough preserved for description.

Genus SANDRIA Brusina.

Sandria Brusina, Atlas, p. ix, pl. 9, figs. 22–27, 1902. Type, *S. kochi* Brusina, pl. 9, figs. 22–24.

These are small shells, much resembling minute *Bythinella*. I have not been able to find a reference to the earlier description of *S. kochi* or the genus *Sandria*. Three species in a more or less imperfect state of preservation are represented in the Castle Creek material if their resemblance to Brusina's figures may be trusted.

Subfamily LITHOGLYPHINAE.

Genus LITHOGLYPHUS Mühlfeldt.

Lithoglyphus (Mühlfeldt MS.) Hartmann, in Sturm's Fauna Deutschl., vol. 6, Heft 5, p. 57, 1821.
Ziegler, in Menke, Synops., p. 42, 1830. Type, *Paludina naticoides* Ferussac.

Lithoglyphus antiquus (Gabb).

Plate XXVI, Figure 2.

Lithasia antiqua Gabb, Paleontology of California, vol. 2, p. 13, pl. 2, fig. 23, 1865.
White, U. S. Nat. Mus. Proc., vol. 5, p. 100, pl. 5, fig. 4, 1882; U. S. Geol. Survey Third Ann. Rept., pt. 3, p. 59, pl. 32, fig. 4, 1883.

This is one of the most widely distributed and conspicuous members of the fresh-water fauna of the Idaho formation. It is a typical *Lithoglyphus* and the first genuine member of that genus to be reported from the Western Hemisphere. The species reported by authors from South America in the Recent fauna belong to quite different genera.

Lithoglyphus campbelli, Dall, n. sp.

Plate XXVI, Figure 1.

Mouth of King Hill Creek near Glenn's Ferry, Snake River canyon, Idaho, U. S. Geol. Survey station 3486; I. C. Russell; very abundant.

Shell small, solid, with a rather acute apex, a pustular nucleus, and about five well-rounded whorls; suture distinct, the whorl in front of it flattened a little, giving a slightly turrited aspect to the spire; last whorl much the largest, naticoid; surface smooth except for incremental lines; base rounded, imperforate; aperture subovate, simple, the margins sharp, the inner and outer lips connected over the body by a thick layer of callus. Altitude, 11 millimeters; maximum diameter, 8 millimeters; aperture, 6.5 millimeters. U. S. Nat. Mus. catalog No. 333527.

Named in honor of W. H. Campbell, collector of the Castle Creek material.

Family VALVATIDAE.

Genus VALVATA O. F. Müller?

Brusina refers to *Valvata* a considerable number of turbinate shells from the Balkan deposits, figuring them on his Plates XIII and XIV. In general, they appear heavier and thicker than the recent shells familiar to us, and some of them with a different type of sculpture remind one of the marine trochoid *Machaeroplax* Friele. One such specimen occurs partly embedded in the Castle Creek material, the aperture and base inaccessible, the upper surface showing about three whorls encircled by two inconspicuous carinae. It is probable that with a better knowledge of these animals a portion at least of the species will prove to be separable from typical *Valvata.*

Genus APHANOTYLUS Brusina.

Aphanotylus Brusina, Jour. de Conchyliologie, vol. 41, pp. 179, 182, 1893. Type, *A. cossmanni* Brusina, op. cit., p. 185; Atlas, p. v, pl. 14, figs. 22–27, 1902.

These are minute planorboid shells with a closed or nearly closed umbilicus, having a remarkable resemblance to the marine genus *Pseudorotella* Fischer.

Aphanotylus whitei Dall, n. sp.

Plate XXVI, Figure 7.

Castle Creek, Owyhee County, Idaho; W. H. Campbell.

Shell minute, of about two whorls, the nucleus hardly raised above the flattened spire, the surface smooth, the suture inconspicuous, the last whorl rather rapidly enlarging; the aperture subcircular with sharp-edged margin and no lirae internally; base well rounded, imperforate. Diameter, 1.6 millimeters; height, 1.2 millimeters. U. S. Nat. Mus. catalog No. 333528.

Another species, represented by broken specimens in the matrix, has a raised cord running spirally in front of the suture and somewhat separated from it. It is a larger shell than *A. whitei.*

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Professional Paper 132—H

THE RESUSCITATION OF THE TERM BRYN MAWR GRAVEL

BY

F. BASCOM

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Shorter contributions to general geology, 1923-1924
(Pages 117-119)

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THE RESUSCITATION OF THE TERM BRYN MAWR GRAVEL.

By F. Bascom.

In the course of geologic and physiographic work in eastern Pennsylvania, it has seemed to the writer that the time was ripe for the restriction of the term Brandywine formation, now including presumably both Pliocene and Pleistocene gravels, and the reinstatement of the old term Bryn Mawr gravel for a portion of the divided Brandywine. A brief history of the nomenclature and usage involved will show the grounds for the choice of terms.

In 1888 the term "Appomattox" was used by McGee [1] for the "older terrace sediments," and in 1891, in conference with Hilgard [2] and others, McGee correlated these sediments with the deposits of Lafayette County, Miss., which had been assigned to the early Quaternary and which were then called the "Lafayette formation." Since that date the term "Lafayette" has been very generally used. Recent work, however, has shown that the "Lafayette formation" of the type locality in the Gulf region is not Quaternary but of Wilcox Eocene age. A new name was therefore proposed in 1915 for the Atlantic coast deposits by Clark,[3] who called them the Brandywine formation, from a type locality in the vicinity of Brandywine village, Prince Georges County, Md. The name was defined to cover all the gravels that lie above the Sunderland formation at 200 feet, in Maryland reaching an altitude of 480 feet and having a width from northwest to southeast of 40 miles. At that time the Brandywine formation was questionably referred to the Pliocene on the ground that it had suffered extensive erosion and that its constituent minerals showed great decay. Clark was himself inclined to think that the deposits were earlier Pleistocene rather than Tertiary. In thus naming these deposits it was the intention to replace by a term signifying a specific age and stratigraphy older terms which included deposits at that time recognized to be of different ages. The term Brandywine itself, however, has in turn been found to cover deposits of more than one level and age.

In 1920, in the Elkton-Wilmington geologic folio,[4] the Brandywine formation was for the first time separated into early (high-level) and late (low-level) Brandywine. The early Brandywine gravels are found in the Elkton-Wilmington district at an altitude of 380 feet, capping Egg Hill and other outstanding hills on the western border of the Elkton quadrangle. The late Brandywine gravels lie at altitudes of 220 feet or more. As the firm hard layers and decomposed pebbles of the early Brandywine gravels indicate a greater age than the Pleistocene, they were referred to the Pliocene (?), and it was stated that the later gravel, though provisionally included with the Brandywine formation, might be of early Pleistocene age. The deposit at the type locality in Maryland is the low-level (200–300 feet) or late Brandywine, presumably of Pleistocene age, as Clark was led to believe; the high-level gravels (390–480 feet) are presumably of Pliocene age. Such a time interval between the early and late gravels as is now recognized has made it infeasible to treat the deposits as a unit. It is therefore proposed to restrict the term Brandywine formation to the late or lower-level deposits of the type locality, and to reinstate the old term Bryn Mawr gravel for the early or high-level deposits of Pennsylvania, Delaware, and Maryland (Cecil County).

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[1] McGee, W J, Three formations of the middle Atlantic slope: Am. Jour. Sci., 3d ser., vol. 35, p. 328, 1888.

[2] Hilgard, E. W., Orange sand, Lagrange, and Appomattox: Am. Geologist, vol. 8, pp. 128-131, 1891.

[3] Clark, W. B., The Brandywine formation of the middle Atlantic Coastal Plain: Am. Jour. Sci., 4th ser., vol. 40, p. 499, 1915.

[4] U. S. Geol. Survey Geol. Atlas, Elkton-Wilmington folio (No. 211) p. 12, 1920.

The history of the term Bryn Mawr is as follows: Carvill Lewis first proposed the term for the deposits of gravel and ironstone conglomerate on the "Upland Terrace" of eastern Pennsylvania. The report upon these gravels, which was made to the Academy of Natural Sciences of Philadelphia in November, 1878, and published in 1880,[5] contains the following descriptions:

> This hill is easily recognized where uncrossed by creeks, being remarkably straight and of uniform height. Being the first hill of importance west of the Delaware, it often commands a fine view and is a favorite site for residences.
>
> The geographical position of this ancient terrace may be more exactly defined in the vicinity of Philadelphia as the hill which crosses Second Street Pike near Foxchase * * * and runs north of Kellyville, Clifton, and Morton, to Swarthmore College and thence past Village Green into Delaware.
>
> This hill, which is approximately parallel not only to the river [Delaware] but also to the shore of the Atlantic Ocean and the line of strike of the Cretaceous formations of New Jersey, forms, as we have seen, the main dividing line between the ancient and the modern formations.
>
> We shall call it for convenience "the Upland Terrace."

A description of the Pleistocene clays and gravels deposited between the "Upland Terrace" and Delaware River follows, and then the report continues:

> Upon the summits of some of the highest hills in the gneissic region back of Philadelphia, at a mean distance of about 9 miles from the river and at elevations of from 325 to 450 feet above it, there are isolated patches of an ancient gravel, different from any yet described, to which we have given the provisional name of "the Bryn Mawr gravel." It can always be recognized by the presence of sharp or partially rounded fragments of a hard, heavy iron sandstone or conglomerate. Such fragments are often covered by a brownish-black iron glaze. More than ten years ago the writer noticed in the soil of the upper part of Germantown pieces of this conglomerate, unlike any known rock, and it is only of late that its origin has been suspected. It consists of well-rounded pebbles of quartzite or siliceous sandstone cemented by iron into a stone which is often very hard. This conglomerate is found in occasional fragments upon ground over 300 feet high but is not found in abundance until an elevation of over 400 feet is reached. At these highest points it occurs in a red gravel whose pebbles are identical with those of the conglomerate. * * * A similar tract of this gravel occurs at Bryn Mawr, extending from that place to near Cooperstown. A good section is exposed in the railroad cut below the station. From this locality, so easy of access from the city, we have named the formation. It is here about 450 feet high and 9 miles from the river. The gravel is 10 feet deep and lies upon a steeply dipping gneiss so completely decomposed that it is as soft as clay.

At a later meeting (March, 1879) Lewis reported that "the Upland Terrace has now been traced continuously from near Trenton, through Bucks, Philadelphia, and Delaware counties to beyond Wilmington in Delaware." He calls attention to

> the great development of the Bryn Mawr gravel in Delaware, and to the indications of its assuming an important position in the geology of the Southern States. * * * Numerous hills in Delaware County have been found to be capped by this formation, and in northern Delaware it covers the gneissic hills in patches several miles long and comes close to the river. * * * This formation so abundant in Delaware is thus proved to be by no means a local one, and it is probable that it will be identified with some of the formations grouped together under the name of "Southern drift."[6]

It is plain from this account that by the "Upland Terrace" was meant the upland the lowest slopes of which are at the 300-foot level, separated by an escarpment from the lower terrace upon which lie the low-level Brandywine deposits and rising to the northwest to the 480-foot level, with a dominating level of 400 feet; and that by the term Bryn Mawr gravel was meant the gravel and ironstone conglomerate capping the interstream areas of this terrace. The gravels of the type localities described by Lewis are plainly the high-level or early Brandywine gravels, and the term Bryn Mawr as used by Lewis covered only the high-level Brandywine deposits as they occur in Pennsylvania and Delaware. The term received considerable usage prior to the introduction of the designation "Lafayette." The Second Pennsylvania Geological Survey referred to the Bryn Mawr gravel as Tertiary or Upper Cretaceous. McGee at first regarded it as of Columbia age and later classified it as lower Potomac.

The term Bryn Mawr gravel is here proposed for the high-level Brandywine because it has the claim of priority, preceding in usage all other designations for the Tertiary deposits of the Atlantic slope, because the gravels of the type locality are the older gravels, and because the 400-foot terrace, upon which the early Brandywine deposits lie, is so prominent a physiographic feature in eastern Pennysylvania, where these gravels and terraces were so early described and given a local name.

---

[5] Lewis, H. C., The surface geology of Philadelphia and vicinity: Acad. Nat. Sci. Philadelphia Proc., vol. 32, pp. 258-272, 1880; see also pp. 277-278, 288, 296-309.

[6] Op. cit., pp. 277-278.

The correlation of the Bryn Mawr formation with other Tertiary gravels near the fall line depends upon the origin of the gravels and upon their topography. Whatever origin is eventually ascribed to the high-level Brandywine by those at work on the Tertiary and Pleistocene deposits of the Atlantic coast, it will doubtless be required to explain acceptably all the high-level gravels, so similar are these deposits and so uniform are the levels upon which they are found.

That these high-level gravels were originally deposited in detached areas is quite possible, but their approximate equivalence is so little to be doubted that until it is disproved the less misleading and less cumbersome method would seem to consist in the use of a single term. The logical alternative is to give a separate name to every patch of gravel above the low-level or typical Brandywine—that is, above the 300-foot level—an alternative which would lead to confusion and which would not reflect the present state of our knowledge.

○

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Professional Paper 132—I

ORIGIN OF THE BOGHEAD COALS

BY

REINHARDT THIESSEN

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ORIGIN OF THE BOGHEAD COALS.

By Reinhardt Thiessen.

The bituminous rocks of sedimentary origin may be classified roughly under two main heads—coals and bituminous shales. In a strict sense no definite line can be drawn between these two groups, because coals may insensibly grade into bituminous shales. Chemically the boghead coals are preeminently bituminous.

COAL.

Coal is composed in the main of the residues of the components of plants. The residues of the ligno-cellulosic components—that is, the woody portions—form the larger part. With these are always associated in varying amounts the residues of the more resistant components and products of plants, of which the resins, resin waxes, fats, and oils or their derivatives are the most abundant. Besides these, many other resistant plant products, too many to enumerate, enter into the formation of coal. The mineral content of coal is relatively low.

BITUMINOUS SHALE.

A shale is generally defined as a rock formed by the consolidation of clay mud or silt, having a finely stratified, laminated, or fissile structure. Some sand is usually mingled with the silt. If such a rock contains organic matter and is dark colored it is termed carbonaceous shale; if the organic matter is of a bituminous nature (highly hydrogenous) the rock is called bituminous shale; and if the rock is rich enough in bituminous substances to yield oil and gas in relatively large amounts on distillation it is called oil shale. The mineral matter in bituminous shales may vary greatly; in oil shales the organic matter is generally less than the mineral matter. Rock in which the mineral and organic matter are approximately in equal proportions may be called cannel slate or cannel shale; and rock in which the organic matter is considerably more abundant than the mineral matter is generally called cannel coal.

Under bituminous shales, therefore, are here considered all bituminous rocks usually designated cannel coals, boghead coals, oil shales, torbanite, tasmanite, and cannel "slates." These rocks have never been classified satisfactorily in accordance with their genetic characters; it is impossible to classify them definitely according to their general appearance and physical properties. However, they may be classified definitely and specifically into several well-defined groups, according to their origin or the origin of their predominant constituent or constituents.

The chief components of organic shale are humic matter—that is, ligno-cellulosic and other matter formed by the degradation of carbohydrates—resinous matter, spore matter, cuticular and other ceric matter, and oil-algal matter. It contains also small amounts of certain other components of unknown origin.

According to their origin, therefore, the bituminous sedimentary deposits may be classed as (1) humic, if the predominant organic constituent is matter derived from the degradation of carbohydrates—that is, such substances as wood, cellulose, lignin, bark, or suberin, gums, mucilage, and starch; (2) spore, if the predominant organic matter is derived from spores; (3) ceric or waxy, if the predominant organic matter is derived from the waxy substances of plants, including oil or fat; (4) resinous, if the predominant organic matter is derived from the natural resins of plants; (5) algal, if the predominant organic matter is derived from oleaceous algae, as in the boghead coals.

Each of these substances is invariably admixed with one or more of the others in different proportions. Usually one predominates, but two or even three components may be present in equal or about equal proportions, with others in less amounts.

THE BOGHEAD COALS.

Boghead coals differ little from any other bituminous shales in outward appearance, and it is often difficult if not impossible to distinguish them. They are close grained, brownish black to black, very tough, elastic, and difficult to break; usually they break with a conchoidal or subconchoidal fracture. In mass they show definite layering, but they will rarely split along definite horizontal planes.

When examined under the microscope in thin sections boghead coals are at once found to differ from all other bituminous shales in that they contain or are composed largely of peculiar irregular oval yellow bodies, through the structure and composition of which they are easily distinguishable from all other bituminous rocks.

Other names have been applied to these deposits, such as kerosene shales, torbanite, torbanehill mineral, brown cannel coal, bathvillite, algal coal, albertite, bituminite, parrot coal, and cannel coal. But as the term "boghead coal" has been most often used, has in general been so consistently applied to deposits of this type and is so thoroughly incorporated into the literature, it can not well be discontinued, although it is not satisfactory. It is used in this paper for want of a better name.

NOMENCLATURE.

The term "boghead" was first applied to coal of this variety found on the Boghead estate, near Bathgate, Linlithgow, Scotland. At Torbane Hill, also near Bathgate, it was called "torbanehill mineral" and "torbanite."

"Kerosene shale"[1] was first applied to boghead coals by the oil-shale industries of Mount Kembla, near Wollongong, New South Wales, Australia, and became identified with the industries at other localities and in other countries. The term is still used in Australia. "Kerosene coal" is a term used by J. R. M. Robertson,[2] of Scotland.

"Wollongite" was proposed by B. Silliman[3] for the substance found at Hartley, New South Wales.

"Petroleum-oil cannel coal" is a term applied by John Mackenzie[4] to the Australian deposits.

"Bituminite" is a name proposed for torbanite by T. S. Traill.[5]

"Parrot coal" is a Scotch term arising from the crackling noise produced when torbanite is placed in the fire.

"Cannel coal," a corruption of "candle coal," was first applied to torbanite because of its property of burning with a clear flame, like a candle, and later became a synonym of torbanite and boghead. The term was soon applied to all coals of similar texture and appearance and so became a generic instead of specific term.

"Brown cannel" was later used by W. B. Clarke[6] to distinguish a boghead from ordinary cannel coal.

"Algal coal" was applied to the boghead coals by Bertrand and Renault.[7]

DISCOVERY AND EARLY HISTORY.

Torbanite was discovered at Torbane Hill, Linlithgowshire, Scotland, in 1850, and later was found at Boghead, Bathville, Inchroos, and Cappers, all near Bathgate, in Linlithgowshire. It was soon found to be a substance exceedingly rich in oily constituents and on this account was brought into special industrial prominence both in Europe and in America. It was about this time that, the patents of Dr. Albert Gesner[8] having been sold to the North American Kerosene Gas Light Co., kerosene was manufactured from coal and introduced generally to the American public. This kerosene or "coal oil" was objectionable on account of its unpleasant odor, and therefore large quantities of torbanite were shipped to America for the manufacture of kerosene that would not have the odor. This led to litigation over patent rights both in America and in England. In England the oil made from torbanite was called "paraffin oil" and was used in "mineral-oil lamps." The litigation over the patent rights led to the institution of a lawsuit that became famous—that of Gillespie *v.* Russel. The dispute concerned the question whether torbanite was coal or not coal and affected the ownership of the deposits. A large number of scientific men in Europe were brought before the court to decide whether the so-called boghead coal is coal or bituminous clay, and the suit incidentally led to the study of the origin of this substance.

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[1] Carne, J. E., The kerosene-shale deposits of New South Wales: New South Wales Geol. Survey Mem., Geol. No. 3, Dept. Mines and Agr., 1903.

[2] Robertson, J. R. M., Min. Inst. Scotland Trans., vol. 14, pt. 6, pp. 88–112, 1892.

[3] Silliman, B., Am. Jour. Sci., 2d ser., vol. 48, p. 85, 1869.

[4] Mackenzie, John, Mineral production of New South Wales, 1887; New South Wales Dept. Mines and Agr., Annual report for 1887.

[5] Traill, T. S., Roy. Soc. Edinburgh Trans., vol. 21, pp. 7–13, 1857.

[6] Clarke, W. B., Geol. Soc. London Quart. Jour., vol. 22, p. 446, 1866, and elsewhere.

[7] See footnote 18, p. 124.

[8] Gesner, G. W. (son of Albert Gesner), A practical treatise on coal, petroleum, and other distilled oils, 1865.

Quecket [9] maintained that torbanehill mineral is not a coal; that it is not like any of the combustible substances used in Great Britain as coal; that, although possessing some of the properties of coal, it is nevertheless a mineral having a basis of clay which is strongly impregnated with a peculiar combustible substance; and that any plants found in it are accidental and have no more been concerned in the formation of the mineral than a fossil bone in that of the rocks in which it may be embedded.

Bennett's opinion [10] was that the torbanehill mineral, although it presents essentially no trace of vegetable structure, is rich in bituminoid substances—a circumstance explained by the fact that it is found in the neighborhood of coal, so that the bituminoid or resinoid matter formed in the partly woody structure of the coal has flowed out, mixed itself with, and solidified in the essentially earthy substance of the torbanehill mineral.

Balfour [11] maintained that torbanite was of the same class as black cannel coal.

OTHER EARLY WORK ON BOGHEAD COALS.

Redfern,[12] lecturer in anatomy, physiology, and histology in the University of Aberdeen, supported the plant origin of the torbanehill mineral and argued that it is like all other cannel coals. Speaking of the yellow bodies of which the mineral is largely composed, he said that he knew of no other interpretation except that they are produced by free vegetable cells, such as spores or pollen grains, yet he could not confidently affirm that they are such; but whatever they may be, they are always to be found in other cannel coals.

The kerosene shale in Australia was discovered long before that in Scotland. Probably the earliest reference to it was published in Paris in 1807, after the return of a French scientific expedition that visited Australia in 1802. It was not utilized, however, until 1865. David,[13] a professor in the University of Sydney, New South Wales, was the first to investigate the kerosene shale of Australia by the most advanced methods of research and the first to propound the hypothesis that this shale is of fresh-water algal origin. The first scientist, however, to suggest the algal origin of the very richly bituminous shales was T. S. Ralph,[14] who claimed that the organic matters forming tasmanite were algae; but in this he was incorrect, as tasmanite is described as a spore cannel coal.[15]

Clarke [16] thought that kerosene shale unquestionably resulted from local deposits of resinous wood and passed gradually into ordinary coal. Dixon [17] argued that the idea of resinous origin must be abandoned, as the resins yield aromatic products and not paraffins. He also thought it more probable that the shales came from oil-producing or wax-producing plants, most likely the latter, in view of the considerable yield of solid paraffins from the shales.

The algal theory of the origin of the boghead coals was most prominently developed by Renault and Bertrand, and the result of their investigations ranging over 25 years was summed up by Renault.[18] A fundamental jelly, a sort of gelatinous precipitate, supposed to have existed in the ancient lakes, pools, and swamps, is one of the chief assumptions in their theory. In this jelly were suspended spores, pollen grains, plant cells, cuticles, and minute vegetable débris, but paramount were certain gelosic algae surrounded by a gelatinous sheath or matrix, something like the *Nostoc* of to-day. Besides these, certain secretive cells are supposed to have been held in suspension, still presenting in detail their protoplasmic and nuclear contents. The fundamental jelly is supposed to have been produced by the action of microorganisms upon the organic matter, possibly upon the algae themselves. It is the essential part of all coals, and the algae, spores, pollen grains, and other minute bodies are merely accidental; one or another of these nonessential constituents may predominate, thus determining the particular character of the coal.

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[9] Quecket, John, On the minute structure of a peculiar combustible mineral from the coal measures of Torbane Hill, near Bathgate, Linlithgowshire, Scotland, known in commerce as Boghead cannel coal: Micr. Soc. London Trans., vol. 2, pp. 34–36, 1853.

[10] Bennett, J. H., An investigation into the structure of torbanehill mineral and of various kinds of coal: Roy. Soc. Edinburgh Trans., vol. 21, pp. 173–185, pls. 1–2, 1857.

[11] Balfour, J. H., On certain vegetable organisms found in and from Fordel: Roy. Soc. Edinburgh Trans., vol. 21, pp. 187–193, 1854.

[12] Redfern, P., On the nature of torbanehill and other varieties of coal: Micr. Soc. Quart. Jour., 1855, pp. 106–127.

[13] David, T. W. E., Note on the origin of kerosene shale: Linnean Soc. New South Wales Proc., 2d ser., vol. 4, pp. 483–500, 1889.

[14] Ralph, T. S., Royal Soc. Victoria Trans., 1865, p. 4; cited by Carne, J. E., The kerosene-shale deposits of New South Wales; New South Wales Geol. Survey Mem., Geol. No. 3, p. 61, 1903.

[15] Newton, E. T., On tasmanite and Australian white coal: Geol. Mag., vol. 2, pp. 337–342, 1875; New South Wales Dept. Mines Ann. Rept. 1879, p. 33.

[16] Clarke, W. B., Industrial progress of New South Wales, 1871, p. 449; cited by Carne, J. E., op. cit., pp. 59–61.

[17] Dixon, W. A., Australasian Assoc. Adv. Sci. Proc., vo. 1, p. 134, 1887; cited by Carne, J. E., op. cit., p. 61.

A careful distinction is therefore drawn by these two investigators between boghead and cannel coals. In the boghead coals the suspended matter consists chiefly of gelosic algae; in the cannel coals it consists of spores. Between the two are found all grades of mixtures, and there may be boghead cannel coals where the algae are more abundant than the spores and cannel bogheads where the spores are more abundant than the algae.

The size of the yellow bodies composing the boghead coals is only a little smaller than it must have been when living. As the mass in the known living gelosic algae contains only a small percentage of solid matter, the remainder being water, it seems clear that such algae could not form the mass of the yellow bodies as found in the bogheads. In order to account for this discrepancy, the algae are supposed to have had a great affinity for bituminous substances and to have been impregnated with and enriched by them to the extent of the present volume. No satisfactory explanation is offered for the origin of the bituminous matter, but probably it was produced by the decomposition of the algae themselves through bacterial activities.

This theory was widely accepted at one time, although some refuted it, foremost among whom was Jeffrey,[19] who concluded from the study of numerous thin sections made from an abundance of material that the bodies interpreted as algae by Bertrand and Renault are not algae but the highly sculptured walls of the spores of cryptogams. When sufficiently thin sections of the bodies in question are cut tangentially through the sculptured spore coats the resemblance to certain algal structures is made very plain. Reconstructions made from serial sections were thought to afford additional evidence of the true spore nature of these bodies by their alveolar structure and triradiate markings and their occurrence in tetrads. With reference to the larger "supposed algae" Jeffrey does not make his case so satisfactory, presumably owing to the distorted condition in which they exist and the difficulty of interpreting thin sections of a larger size. But he presents the apparently reasonable argument that if those which are best preserved and by reason of their size are most easily studied in thin sections of coal prove not to be of algal affinities, a similar conclusion must be applied to the remaining organisms, which either by their large size or their imperfect condition of preservation can not be satisfactorily subjected to microscopic investigation.

At first Zalessky[20] supported Jeffrey's opinion, which he thought was confirmed by examination of a preparation of a siliceous nodule found in the boghead of Autun. The alga, *Pila bibractensis*, seemed to him to be a spore with a reticular sculptured surface, and the walls of the supposed cells seemed to have the form of ribs jutting out on the surface of the spores. Studies of material sent to him later by Bertrand and Combray changed his opinion to one in support of Renault and Bertrand's algal theory. In preparations of these siliceous boghead samples he clearly observed the cellular *Pila* structure, as if occurring in a more or less natural state in the bog, giving good evidence to accept that these cellular bodies are algae.

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[18] Renault, B., Sur quelques microorganismes des combustibles fossiles. Soc. ind. min. St.-Étienne Bull., 3d ser., vol. 13, pp. 895–1191, 1899; vol. 14, 456 p., 66 figs., 30 pls., 1900.

See also Bertrand, C. E., Le boghead d'Autun: Soc. ind. min. Bull., vol. 6, pp. 453–506, 1892; Bertrand, C. E., and Renault, B., *Pila bibractensis* et le boghead d'Autun: Soc. hist. nat. Autun Bull., vol. 5, pp. 159–253, 1892; Bertrand, C. E., and Renault, B., *Reinschia australis* et premières remarques sur la kerosene shale de la Nouvelle-Galles du Sud: Soc. hist. nat. Autun Bull., vol. 6, pp. 321–425, 1893; Bertrand, C. E., Nouvelles remarques sur le kerosene shale de la Nouvelle-Galles du Sud: Soc. hist. nat. Autun Bull., vol. 9, pp. 193–292, 1896; Bertrand, C. E., Conclusions générales sur les charbons humiques et les charbons de purins: Compt. Rend., vol. 127, pp. 822-825, 1898; Bertrand, C. E., Description d'un échantillon de kerosene shale de Megalong Valley, N. S. W.: Linnean Soc. New South Wales Proc., vol. 25, pp. 617–649, 1901.

[19] Jeffrey, E. C., The nature of some supposed algal coals: Am. Acad. Arts and Sci. Proc., vol. 46, pp. 273–290, pl. 1–5, 1910.

[20] Zalessky, M. D., On the nature of the yellow bodies of boghead, and on sapropel of the Ala-Kool Gulf of the Lake Balkash: Com. géol. Bull., vol. 33, pp. 495–507, Petrograd, 1914; Flore gondvanienne du bassin, de la Petchora, I, Rivière Adzva: Soc. ouralienne amis sci. nat. Bull, vol. 33, 1913.

As illustrating the nature and origin of boghead coal Zalessky offers an example from the plant world of to-day in an alga, which he calls *Botryococcus braunii*,[21] growing in the brackish, shallow Ala-Kool Gulf, overgrown with marsh and aquatic plants, at the southern extremity of Lake Balkash, in Turkestan. This alga, bearing a considerable amount of oil, comes to the surface of the water. Zalessky states that when these algae accumulate on the shore, a hydrogen sulphide fermentation takes place; and finally, when in contact with the air, they dry and change from a dark-green into a yellow-brown elastic, rubber-like mass, which can be easily cut with a knife. Thin sections of this mass sometimes clearly show the structure of the algae, which much resemble the bodies in the siliceous boghead sample examined. From this observation deductions are made as to the origin of the bogheads. A further study of the habits of the algae and their transformation into the elastic mass had not been made.

Similar conclusions[22] are drawn from a study of sapropelic substances found at the bottom of Lake Bioloe at Tver, Russia, in a deposit 9 meters thick, said to be composed of blue-green algae, principally of the genera *Microcystis, Aplanocapsa, Alphanatheca, Chroococcus, Gleotheca, Synechococcus;* and of the green algae *Scenedismus obliquus*, *Scenedismus bijugatus*, and *Pleurococcus vulgaris*.

Later Zalessky[23] found that the bituminous rock of the "Lower Silurian" in Petrograd and Esthonia along the Baltic coast, called kukersite, were similar in nature to the boghead shales of Autun. The fossil organisms in these rocks have a structure very similar to that of the blue-green algae of the genus *Gloeocapsa*, and Zalessky therefore proposed the name *Gloeocapsamorpha prisca* for them.

Conacher[24] examined the oil shale and torbanite of England and Scotland and concluded that they are derived from the same substances as coal but that in the shale there has been a much larger elimination of the woody matter, leaving a large proportion of resinous matter mixed with sand.

In 1914 the present writer [25] maintained that no algae were found in any of the boghead coals he investigated, although many of the bodies called algae by various investigators were found. Many of these, however, were shown to be spores; others were of unknown origin. Some of Renault's illustrations of *Reinschia*, showing both cross and horizontal sections, were certainly those of spore exines. The weakest points in Renault and Bertrand's algal theory, however, were those clauses relating to the "fundamental jelly" and the "bituminous affinity" of the algae. No algae having the structure revealed by the yellow bodies in the boghead coals were known to the writer, nor any that had as massive a cell wall as those in the bogheads indicated. Ordinary living algae, as well as those in the ancient swamps referred to as being analogous, contain at the most only a small quantity of solid matter, by far the largest part of their mass being composed of water. Also, the cell walls of ordinary algae are of pectic-cellulosic nature—that is, they are carbohydrates, which are readily attacked by putrefying organisms and are quickly decomposed under ordinary conditions. Any algal bodies that might have been preserved in the coals would be represented by only an exceedingly thin residue. Renault and Bertrand probably also realized this difficulty, and to overcome it they propounded the hypothesis of bituminous affinity, through which the gelatinous cell walls of the algae were supposed to have absorbed a certain amount of bituminous substances, to account for their solidity and relative massiveness as represented by the yellow bodies in the coals. The fundamental jelly in which these bodies were supposed to have been suspended has never been observed by the writer. These points—namely, the structure and chemical nature of algae as then known and the unacceptability of the hypotheses of bituminous affinity and the fundamental jelly as proposed by Renault and Bertrand—were sufficient in the writer's mind to overthrow the algal theory.

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[21] Zalessky, M. D., On the nature of *Pila* of the yellow bodies of boghead and on sapropel of the Ala-Kool Gulf of the Lake Balkash: Com. géol. Bull., vol. 33, pp. 495-507, Petrograd, 1914. Litinsky, L. L., Balchash-Sapropelite: Petroleum, vol. 17, pp. 437-440, 1921.

[22] Zalessky, M. D., Soc. paléont. Russie Annuaire, vol. 1, pp. 25-42, 1916.

[23] Zalessky, M. D., Sur le sapropélite de l'âge silurien formé par une algue cyanophycée: Soc. paléont. Russie Annuaire, vol. 1, pp. 25-42, 1916.

[24] Conacher, H. R., A study of oil shales and torbanites: Geol. Soc. Glasgow Trans., vol. 16, pt. 2, pp. 164-192, 1917.

[25] White, David, and Thiessen, Reinhardt, The origin of coal: U. S. Bur. Mines Bull. 38, p. 277, 1914.

On the other hand, the writer could not agree that the yellow bodies in the bogheads were invariably spores. The kerosene shales of New South Wales, the typical *Reinschia* coals, stood out most clearly as contravening the theory of spore origin, and the bodies of unknown origin in the cannel coal from the Pottsville of Kentucky could not be classed as spores. For this reason the boghead and cannel coals have been objects of thought and investigation from time to time. Their nature and structure have now been fairly well worked out.

The boghead coals that have been studied were the kerosene shales from Newnes, New South Wales; bogheads from Torbane Hill and from Bathgate, both in Scotland; and American bogheads from Alaska and from Kiskiminetas Junction, Pa.

STRUCTURE OF THE YELLOW BODIES COMPOSING CERTAIN BOGHEAD COALS.

The organism that gave rise to these boghead coals was colonial—that is, a number of individuals were united into a larger body. (See Pls. XXXII–XXXVII.) In many places a number of such colonies were united into a larger mass. Some of the colonies were apparently in the form of a hollow sphere.

The protoplasmic or living part of the organism was of an oval form, as shown in thin sections and illustrated in Plates XXXIII, *B;* XXXIV, *A;* XXXV, *B;* XXXVI–XXXVIII, *A*, and was surrounded by a relatively thick cell wall. This constituted a unit cell or organism. A considerable number of these were joined together into spherical bodies or colonies by a matrix of slightly different character. Whatever the nature of the cell wall and its cementing matrix, they were resistant enough to withstand weathering, putrefying, and oxidizing agencies and the coal-forming processes so well as to retain more than half of their original volume. Their structure points clearly to an organism other than spore matter of any plant.

THE BOGHEAD-FORMING ORGANISM.

The kind of organisms that gave rise to the bogheads is clearly represented by an oil-bearing organism now living in salt lakes and salt lagoons of South Australia and surrounding islands. A recent study of this organism has shed much light on the nature of the yellow bodies composing the boghead coals and on the formation of the bogheads themselves.

The exact position of the organism in the plant kingdom, together with its life history and habits, are yet unknown and are still under investigation. It resembles in some respects certain of the blue-green algae, but in the nature and chemistry of the cell wall it differs greatly from the ordinary blue-green algae.

As no family or genus group to which this organism could be assigned is described in monographs such as Engler and Prantl's "Die natürlichen Pflanzenfamilien" or Toni's "Sylloge algorium," a new name had to be found for the organism. The name *Elaeophyton*,[26] meaning oil plant, is therefore suggested. As the plant examined was found near The Coorong, the specific name *coorongiana* is also proposed.

At the end of each winter a green scum called "seepage material" is formed on the lakes and lagoons and is blown by the prevailing winds to the southeastern shores. As the hot weather progresses and the lakes dry up this material is deposited on the sand of the bank and quickly dries and solidifies into large sheets of a rubber-like dark-brown material, called coorongite. This material has been the object of much discussion, and all endeavor to discover its origin has heretofore been unsatisfactory.[27]

Samples of both the green seepage material and the coorongite were obtained through the courtesy of Mr. John Claffey, of Adelaide. The organisms are colonial: a considerable number of unit individuals or cells are associated into colonies and form globules just visible to the naked eye. (See Pl. XXVII, *A*.)

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[26] On account of the resemblance of this organism to forms that are often termed cocci and the large amount of oil it yields, the name *Elaeococcus* was first proposed for it by the writer and has appeared in print. But it was found that the term *Elaeococca* had been applied by Moritz Hill to one of the Euphorbiaceae found in Japan and China, *Elaeococca vernicia*. The name *Elaeococca* therefore has priority over *Elaeococcus*, which had to be abandoned.

[27] Data from personal communication from John Claffey, of Adelaide, South Australia.

These colonies may be either single or compound; in the latter type a number of single or primary colonies are united. A number of colonies may be coalesced into larger globules (Pl. XXVII, *A*), or a larger number of colonies may in turn be united into a large mass (Pl. XXVII, *B*). Plate XXVIII, *A*, represents a stained colony at a high magnification, somewhat flattened under the cover glass.

The structure may be best seen through stained thin sections. The section of a single colony, as on Plate XXVIII, *B*, shows it to be composed of an outer zone of living cells, usually several cells deep, irregularly forming a thick spherical shell. This shell incloses a number of irregular cells of variable size and without protoplasmic contents, thus forming a central blank core. Plate XXVIII, *B*, shows several colonies. Usually several primary colonies are coalesced into secondary or compound colonies, in which the central blank cores of the primary colonies are in communication with one another. (See Pl. XXIX.)

The protoplasmic or living part of the cells is of an oval shape and relatively small, not over 5 microns (0.0002 inch) in length and 3 microns in diameter. No definite nucleus is distinguishable, but the whole cell content takes up a nuclear stain and is shown as a granular mass. In the living condition it contains chloroplasts of a blue-green color (Pls. XXX, XXXI). The protoplasmic part is surrounded by a relatively thick colorless cell wall of a clear and not particularly firm consistency, which stains with difficulty. The cell walls of the several individuals are cemented together by slightly denser matter of similar appearance, which, however, stains more readily (Pl. XXXI). As shown in Plates XXVIII, *B*, and XXIX, the active living cells are formed irregularly into a thick zone, several to many cells deep, inclosing a group of blank cells in the center. These central blank cells are on the whole larger but are more variable in size, are irregular in shape, and together form a looser structure than the outer living cells (Pls. XXIX, *B;* XXX; and XXXI, *B*).

Where several colonies are united into larger secondary colonies, the cells at the junction have either lost their protoplasmic contents or have been squeezed out and replaced by the central blank cells. (See Pl. XXIX, *A*.) A colony or a larger number of colonies form a soft, flexible, but not mobile nor waxy mass. When they are placed under a cover glass considerable pressure is required to flatten or spread them out.

The cell walls lend the organisms their peculiar properties. They do not decay or putrefy when exposed to the air in mass but congeal into a rubbery, elastic mass, which does not undergo further marked changes and, as already noted, forms the substance called coorongite. They are not composed of pectin, mucin, pectocellulose, or mucocellulose, as in ordinary algae, but consist largely of oils or oily substances, the nature of which is under investigation.

COORONGITE.

ORIGIN.

There can be no doubt that coorongite is formed from the green seepage material or mass of living *Elaeophyton.* When a mass of the green living organisms is exposed to the air it quickly changes its color to a dark brown or grayish black and congeals to an elastic, rubber-like mass, exactly like the coorongite, in which the colonies and individual organisms and their structure are more or less clearly discernible, together with a small amount of extraneous matter, like sand grains, bits of plant tissues, cuticles, diatoms, and other algae.

Coorongite as received from the field is plainly seen to be composed of the same organisms and contains the same kind of extraneous matter. Some of the colonies and individual cells of the organism are very well preserved, others not so well; but even in the most poorly preserved material the characteristic structure is still recognizable.

HISTORY.

Coorongite was discovered in 1865 on the shores of The Coorong, in South Australia. It has been variously known and described as Australian caoutchouc, mineral gumboge, elaterite, elastic bitumen, and coorongite, and it has been the object of curiosity and discussion ever since its discovery. The discussions have mostly concerned its origin, whether mineral or organic, and they are so numerous and generally so unauthoritative that it is impossible to give even a summary of the ideas presented. A number of eminent scientists, however, have investigated coorongite and have made reports on it. Among these are Thiselton-Dyer,[28] Boodle,[29] Cumming,[30] Höfer,[31] and Wiesner.[32] An accurate description of coorongite in the field is given by De Hautpick,[33] who says:

> Coorongite is found in the depressed portions of occasionally submerged sandy plains of considerable extent and is spread upon the ground chiefly near the edges of the depressions at the high-tide mark. Coorongite occurs in this district spread over a great area in the form of cake lying on the sand without any connection with the ground on which it is deposited. It represents undoubtedly the solidification of some substance which previously floated on the surface of the water and then was deposited on the sand and gradually dried up, absorbing and uniting with, during the drying process, all matter that happened to come in contact with it. Coorongite is of various thickness from an inch to 1 foot, and in color and appearance it is closely akin to the so-called "paraffin dirt" of the Gulf coast oil fields of Texas and Louisiana.
>
> Coorongite shows a peculiar rubber-like texture. When moist the material breaks much after the fashion of "green cheese." Although rubbery under compression, it does not resemble rubber in tenacity or cohesion, and in this respect it is identical with its twin, the "paraffin dirt" of America. It is clear, then, that coorongite is not a caoutchouc, although in appearance and color it resembles caoutchouc. It is soft, flexible, and easily cut, clammy to the touch, yet does not soil the skin. It has a characteristic "swampy" or "mucky" odor when wet and a characteristic odor of humic soils when moist. If the material is brought into suspension in water, very fine sand settles out and may be recovered by successive washing and decantation. When moist, it is gelatinous but neither markedly adhesive nor plastic. It is easily affected by water but is insoluble therein. In thin slips it burns like a taper, melting before the flame, which is smoky.

A substance very similar to coorongite, called n'hangellite, is found in Portuguese East Africa. Boodle[34] quotes a report made by J. Gething Hancock as follows:

> N'hangellite is an elastic description of bitumen and may be termed a mineral india rubber. It is dark green in color and is lighter than water and has probably been formed in the oxidation of petroleum. It is most prevalent in the plain to the north and northwest of Lake N'hangella and to a large extent may be described, as far as this neighborhood is concerned, as peculiar to that locality.
>
> The n'hangellite in occurrence is generally about half an inch in thickness and lies in patches varying from a few square yards to probably half an acre in extent. It is chiefly found in long, narrow strips on the surface anticlines of slightly undulating ground and gives the impression that it has been washed there by water, having largely the appearance of a high-tide mark. On the other hand, it is occasionally found in small pans, again indicating that it has been taken there by water and remained after the water had subsided. * * * I made the most searching inquiries * * * and was informed by many that after the rains it is possible to see this deposit gradually collecting and that it is then of a light-brown color and gelatinous in appearance.

Boodle's description of n'hangellite is as follows:

> Specimens of this substance, when examined microscopically, prove to consist of a yellowish matrix, in which are embedded diatoms, sand grains, and sometimes sponge spicules, pollen grains, spores, etc.; but these inclusions are unimportant, forming only a small proportion of the mass. Fungal hyphae are also present and are often crowded and very distinct near the surface of the specimens, more sparse and forming an irregular reticulum in the interior.
>
> The yellowish matrix, when examined in thin sections under a high power, is usually seen to contain numerous very small cells, which are more refractive and for the most part more colored than the substance in which they are embedded. The latter may appear colorless in very thin sections, while the cells in question are yellow or brownish or pale green. They are usually elongated, and their sectional shape is elliptical or pyriform, or circular when seen in end view. In length they vary from 2 to 6 microns, or occasionally 8 microns, and their breadth may be about half as great or more. Frequently no definite arrangement can be distinguished, but occasionally in favorable places one can demonstrate that the cells are grouped in colonies, which appear to be roughly spherical when small, elliptical or botryoidal when large. The cells are arranged so that their length is radial with regard to the colony, in which they form a peripheral layer, one or sometimes two or more cells thick. Their lateral distance from one another is variable but generally greater than their own diameter. When rather crowded, they are sometimes clearly arranged in pairs or groups of four. The substance in which the cells are embedded shows no structure and might well be the product of mucilage only. It is only here and there that colonies of definite shape can be distinguished; the scattered arrangement of the cells in other parts of the matrix may be explained as either due to flattening or distortion of colonies of similar form and size, or to the colonies having had indefinite growth, so that only young stages would show a regular form.
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> From such details as can be determined there seems to be no doubt that the matrix has been derived from

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[28] Thiselton-Dyer, W. T., On a substance known as Australian caoutchouc: Jour. Bot., 1872, pp. 103–106.

[29] Boodle, L. A., N'hangellite and coorongite: Roy. Bot. Gardens, Kew, Bull. 5, pp. 146–151, 1907.

[30] Cumming, A. C., Coorongite, a South Australian elaterite: Chem. News, vol. 87, pp. 306–308, 1903.

[31] Höfer, Hans, Das Erdöl und seine Verwandten, pp. 262–264, 1922.

[32] Wiesner, Julius, reviewed by Höfer, op. cit.

[33] Hautpick, E. de, Coorongite, a petroleum product: Australian Min. Standard, 1923, pp. 1000–1001.

[34] Boodle, L. A., N'hangellite and coorongite: Roy. Bot. Gardens, Kew, Bull. 5, pp. 145–151, 1907.

> a gelatinous organism belonging almost certainly to the blue-green algae, among which it would be classed under the Chroococcaceae. Prof. G. S. West, F. L. S., who kindly examined the organism for me, agrees that it certainly appears to be a blue-green alga and compares it with *Coelosphaerium* Naeg. but adds that it is not exactly like anything with which he is acquainted. Its precise determination must be reserved until living material, or such as represents early stages in the formation of n'hangellite, can be obtained. Conversion into bituminous substance must imply extensive chemical changes in the mucilage, whereby the original characters of the alga may have been altered to some extent as regards the spacing and form of the cells. Changes have no doubt also taken place in the cell contents; hence the occasional greenish color of the cells may be secondary and not a remnant of their original pigment. On soaking or boiling a section in water the cells undergo a curious change; their cavities become enlarged and often appear as though empty, but when transferred to strong glycerine they gradually regain their original appearance.
>
> In some parts of the specimens the matrix shows no structure, but as the loss of structure is often not abrupt but preceded by a transitional boundary where the algal cells are collapsed or indistinct, it is probable that the structureless condition is secondary and due to more destructive changes than those which took place elsewhere. One may therefore assume that the whole of the matrix represents a gelatinous alga.

This description tallies very closely with that of coorongite.

CHEMICAL PROPERTIES.

When heated in a tube coorongite will all melt, forming a sirupy liquid, which remains viscous after cooling. On distillation it yields large quantities of oil.

An analysis made in a laboratory of the South Australian Government gave the following results:

Analysis of coorongite.

Moisture and volatile substances at 120° C	0. 8
Gaseous distillates with acid reaction	14. 0
Oily distillate	69. 2
Tarry matter and coke	10. 1
Mineral matter	5. 9
	100. 0

The oily distillate was redistilled and gave a series of oils of varying densities in the following fractions:

Results of redistillation of oily distillate from coorongite.

Fraction at 110° to 170° C	6. 7
170° to 240° C	27. 7
240° to 295° C	25. 3
295° to 300° C	27. 3
Residue	14. 0
	100. 0

An ultimate analysis gave the following results:

Ultimate analysis of coorongite.

Moisture	0. 46
Carbon	64. 73
Hydrogen	11. 63
Ash	1. 79
Fixed carbon	1. 005
Oxygen, etc	20. 375
	100. 00

Analyses made in the Bureau of Mines laboratory at Pittsburgh gave the following results:

Analyses of coorongite.

	As received.	Moisture free.	Moisture and ash free.
Proximate analysis:			
Moisture	1. 6	--------	--------
Volatile matter	90. 1	91. 5	97. 2
Fixed carbon	2. 6	2. 7	2. 8
Ash	5. 7	5. 8	--------
	100. 0	100. 0	100. 0
Ultimate analysis:			
Hydrogen	11. 3	11. 3	12. 0
Carbon	73. 8	75. 1	79. 7
Nitrogen	. 7	. 7	. 7
Oxygen	8. 4	7. 0	7. 5
Sulphur	. 1	. 1	. 1
Ash	5. 7	5. 8	--------
	100. 0	100. 0	100. 0

These figures agree fairly well with a number of determinations made by other analysts.

Coorongite is partly soluble in carbon bisulphide, chloroform, ether, and benzol. A preliminary extraction with carbon bisulphide yielded about 70 per cent of soluble matter. The residue is of a tough, leathery consistency and has lost much of its elasticity. Besides the residue of the oil algae, it contains a few fragments of tissues and cuticles of higher plants, also mineral matter consisting of some diatoms and largely of sand. The ash amounts to 5.8 per cent in the untreated coorongite. All the insoluble extraneous substances have naturally been concentrated in the residue. The soluble matter is in the form of thick, viscous oil of a yellow color, which gradually turns darker on exposure to the air.

Cumming[35] carried the investigations on the extraction with carbon bisulphide further. He obtained 24 per cent extract, leaving a residue containing 30 to 40 per cent of ash. The soluble matter therefore amounted to about 33 per cent of the original coorongite. This consisted of a clear yellow, translucent, waxlike substance, which softened at 35° C. and was quite fluid at 42°. It was readily soluble in all proportions in benzene, ether, toluene, chloroform, and carbon bisulphide. Cumming was not able to saponify it and therefore concluded that it was of the nature of a mineral oil. Its composition (C, 77.92; H, 11.69; O, 10.39) and its molecular weight correspond to the formula $(C_{10}H_{18}O)_8$.

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[35] Cumming, A. C., Coorongite, a South Australian elaterite: Chem. News, vol. 87, pp. 306-308, 1903.

The insoluble constituent was an unelastic, tough substance, which burned with a luminous flame, melted before the flame, and had an odor like burning fat. It was saponifiable with alcoholic potash. Its composition (C, 64; H, 10.52; O, 25.26) and molecular weight conform to the formula $C_{10}H_{18}O_3$. The chemical examination of coorongite and the oil derived from it has not been completed.

CONCLUSIONS.

The study of *Elaeophyton* therefore furnishes proof of the theory of the algal orgin of the boghead coals. The plan of organization, the structure, and even the form and size of the organism agree so closely with the corresponding character of the yellow bodies that constitute the boghead coals as to leave no room for doubt of their close biologic relation and their similarity in composition. The chemical nature of these organisms is so resistant to the agencies of putrefaction as to enable them, in a favorable environment, to survive the coal-forming processes with more or less complete preservation in the forms found in the boghead coals.

The most important fact concerning *Elaeophyton* with reference to the formation of coorongite, in consideration of the theory that boghead coals owe their origin to similar organisms, is the chemical composition of its cell wall. The cell walls in the living organism are composed largely of oil or oily substances. No theory of chemical changes from cellulosic or mucous substances into an oil or fat is necessary. The oil is such in the living plant. There is probably a slight oxidation of some constituents but no radical change. The fact that the cell walls do not appear to putrefy nor undergo any further oxidation after the first change of color seems to account for the more or less complete preservation of the organisms in coorongite.

YELLOW BODIES OF BOGHEAD COALS COMPARED WITH ELAEOPHYTON.

In the light of the structure and other features of *Elaeophyton* as above set forth, we can now return to the boghead coals and by comparison and analogy get a more complete idea of the nature and the structure of the organisms that formed them, and so of the nature, structure, and origin of the fossil bogheads themselves. By comparison of horizontal sections at a lower magnification the similarity is evident. Plate XXXII, *B*, represents a horizontal section of the Australian kerosene shale containing *Reinschia australis*, and in comparing this with Plate XXVII, *B*, showing the living *Elaeophyton*, all magnified at 200 diameters, the resemblance is clearly shown. At a higher magnification, at which the cellular structure is more definitely brought out, the similarity is definitely shown and is seen to correspond to a striking degree. Although almost any of the illustrations will serve, the most surprising similarity is shown in Plate XXXI, *A*, representing the living organism, and Plate XXXIV, *A*, representing a section of the Australian kerosene shale. Plate XXXIII, *B*, illustrating *Reinschia*, also shows a striking resemblance.

It should be remembered that a photograph will not represent all the structural features as clearly as they can be seen directly under the microscope, where, by focusing up and down, the structure may be followed throughout. When the two forms are thus studied, and allowances are made for the changes resulting from coalification processes, no doubt is left as to their common origin.

The yellow bodies in the boghead coals can now be interpreted as colonies and compounds of colonies, exactly as in the living material. The smaller yellow bodies represent primary colonies in the central part of which the blank cells may often be discerned (see Pls. XXXIV, *A;* XXXV, *B;* and XXXVI, *A*); others are fusions of two, three, or four primary colonies, in which also the blank cells may be recognized (Pl. XXXVII, *A*). Probably most of the yellow bodies are of this kind; in others, the large yellow bodies, a large number of colonies are united. The outlines of the primary colonies can usually be distinguished in the compound colonies, as in the living material. (See Pls. XXXIII, *B;* XXXIV, *A;* XXXVI, *A;* XXXVII, *B;* XXXVIII, *A.*)

The protoplasmic or once living parts of the organisms are represented by the darker areas shown in the illustrations, most of them clearly of an oval outline, though some are contorted and disarranged. In thin sections of the boghead coals these portions are shown to be oval or ovoid sacks, or contorted or shriveled-up sacks that once were ovoid. Usually the contents are brown to dark brown. However, in the bogheads from different localities they may vary considerably in state of preservation, color, size, form, and definiteness of outline. In the Scotch torbanite examined, for example, the cell contents of *Pila*, the yellow body, are much lighter in color and may even be of the same color as the cell-wall matter, the coloring matter being absent, so that the cell wall is indicated merely by a line of different refraction. In the Australian kerosene shale the colonies of *Reinschia* are in many specimens particularly well preserved, and the sacks contain much brown coloring matter; for this reason these shales furnish most favorable material for study. Each of the brown sacks is surrounded by a light-colored, usually relatively thick wall, which in turn is embodied in a slightly darker material, the medium cementing the cells into colonies. The oval sacks with their surrounding cell walls are grouped in a zone toward the outside. This zone may be two or more cells deep. Their arrangement commonly is irregular—that is, there is generally no definite orderly arrangement. In this respect they are similar to the living form. At the central part of each of the multiple colonies is found a blank structure—that is, cells without the brown sacks. These undoubtedly are analogous to the blank cells of the living colonies of *Elaeophyton.*

COMPARISON OF THE BOGHEAD COALS EXAMINED.

In comparing with one another the boghead coals studied considerable differences in structure and the degree of preservation may be observed. Many of these differences are, however, possibly due to extrinsic causes and are not differences that existed in the organisms themselves when living.

AUSTRALIAN BOGHEAD, OR "KEROSENE SHALE."

The boghead coal from the Wolgan Valley, New South Wales, in a formation of Permian age, is compact and homogeneous in its outer appearance and shows but little stratification. It is of a dark or dull-brown color, breaks with a typical conchoidal fracture, and can not be made to split along any particular cleavage plane.

As seen in thin sections, the yellow bodies, the colonies of *Reinschia australis,* are somewhat loosely packed. This is shown in Plate XXXII, *A*, in which the bodies are represented by irregular, elongated patches and the groundmass by the black areas. There is, however, a considerable difference in this respect in different parts of the same sample or even in the same thin section. The colonies or yellow bodies have been flattened considerably, the larger ones more than the smaller ones. The ratio of the larger diameter to the shorter averages about 2:1; in the smaller bodies it is 3:1. Most of the smaller bodies represent single colonies; the larger ones represent compound colonies.

The colonies are embedded in an opaque, dirty-looking groundmass, which, in general, is composed of matter produced by organic degradation and a small amount of mineral matter. A large part of this organic matter is the result of degradation of the yellow bodies themselves; besides this, bits of plant tissues and plant fibers and remnants of cuticles form a very small part of it. Spores are not numerous in this boghead but are invariably present, as is to be expected.

The yellow bodies or colonies of *Reinschia* in this sample are the best preserved of all the algae in the boghead coals examined. There is, however, a considerable variation in their state of preservation. In some the structure is remarkably well preserved, every detail of the structure of the organism being intact; in others it is very obscure. Between these two extremes all shades of preservation may be observed. The sacks—that is, the once living protoplasmic contents—contain much brown coloring matter, which differentiates them clearly from the remainder of the cell and also lends the section as a whole a brown color under the microscope.

BOGHEAD COAL (TORBANITE) FROM TORBANE HILL, SCOTLAND.

In its outward appearance the sample of boghead coal from Torbane Hill, Scotland, resembles an ordinary spore cannel coal. It is slightly laminated, and although the cross and oblique fracture is conchoidal in general, it will split along certain horizontal bedding planes. It represents the celebrated deposit of torbanite found in the Calciferous sandstone series, of Mississippian age.

As seen in thin sections, the yellow bodies, the colonies described as *Pila scotica,* are a little more closely packed than the colonies in the Australian shales and are not nearly so much compressed. This is clearly shown in an examination of the photographs of the cross section reproduced in Plate XXXIV, *B,* and in a comparison with the horizontal section in Plate XXXV, *A.* The groundmass is of the same appearance and probably of the same composition as that in the Australian shales, though it is somewhat more opaque. The sacks, or once living protoplasmic parts of the cells, contain little or no brown coloring matter and hence are not well differentiated from the remainder of the cell. That they are present is clearly revealed through a difference in refraction of the cells along the borders of the sacks, although this may not be reproduced distinctly in the photographs; yet every photograph taken shows clear evidence of the structure. The lack of the brown coloring matter makes the sections of a much lighter color than those of the Australian boghead. The algal colonies appear to have suffered considerable changes during the peat stage and look as if they were waterworn. A careful comparison shows that their general structure was very similar to that of the Australian deposit.

Spores are invariably present in this coal, though in relatively small numbers.

BOGHEAD COAL FROM BATHGATE, SCOTLAND.

Only one small sample from the deposit at Bathgate, Scotland, has been examined. Experience shows, however, that one section is indicative of the characteristics of a deposit for a considerable space around the sample. The material is from the Calciferous sandstone series, of Mississippian age.

The yellow bodies (colonies referred to *Pila scotica*) in the Bathgate boghead coal are considerably more flattened than those in the Torbane Hill deposit and have a more pronounced brownish color. (See Pls. XXXVI, *B,* and XXXVII, *A.*) The embedding medium is of the same appearance as that in the Torbane Hill boghead. The structure is much better preserved than that in the Torbane Hill coal but not quite as well as that in the Australian shale. The sacks are well preserved and well differentiated from the cell walls, owing to their dark-brown contents. The structure is very similar to that in the Australian boghead. The differences in preservation are due to outside influences; evidently the organisms that gave rise to the deposit at Bathgate and Torbane Hill were very similar to those in the Australian deposits, to which they are most clearly related.

BOGHEAD COAL FROM ALASKA.

In outward appearance the Alaskan boghead, according to the one sample on hand, is very similar to an ordinary cannel coal. This sample came from a district drained by Colville River; the exact locality and the geologic age of the beds are not known. It is compact and dark grayish black. When examined at a low magnification (200 diameters), it presents the same general appearance as the boghead coals from Scotland and Australia and at once gives the impression that it is of the same kind. (See Pls. XXXVIII, *B,* and XXXIX, *A.*) But under a higher magnification it presents a marked difference, and offhand it gives the appearance of not belonging to the same kind at all. The yellow bodies on the whole are somewhat smaller than in the samples previously described, the large majority have no brown coloring matter in the sacks, and they reveal no definite structure or only a faint structure. But a careful survey of the sections, both horizontal and cross, discloses here and there yellow bodies whose structure has been well preserved and whose entire organization may be reconstructed. These show that the general structure is similar to that in the Australian boghead coal, if not the same, and that they must have been derived from an organism of the same nature as that which gave rise to that coal. Between those that are well preserved and those in which little or no structure has been retained all grades of transition are found; and as the general appearance, nature, and form of all the yellow bodies are the same, it must be concluded that all were derived from the same source.

The alga characterizing the Alaska boghead is almost certainly of the same nature and is probably closely related to those forming the yellow bodies in the other boghead coals here described, as well as the living *Elaeophyton*.

BOGHEAD COALS OF THE KISKIMINETAS REGION, PENNSYLVANIA.

The boghead coal at Kiskiminetas Junction, Pa., in the region where Kiskiminetas River joins Allegheny River, is found in a thin bed, not more than 2 feet in thickness, in the limestone between the Upper and Lower Freeport coals, in the Allegheny formation, of Pennsylvanian age. It begins with an ordinary shale at the bottom, which quickly changes into a bituminous "slate" and then within a few inches into a rich boghead coal. It much resembles a bituminous shale throughout its thickness. (See Pl. XXXIX, *B*.) It is laminated and will split horizontally along certain bedding planes.

In thin sections its resemblance to the other boghead coals is at once apparent. The yellow bodies are, on the whole, of the same size as those in the Alaskan boghead but smaller than those in the Scotch and Australian samples. In general form and appearance the yellow bodies (Pl. XL, *A*) are the same as those in the other bogheads, but on comparison of the minute structure they are found to differ markedly, showing very little organized structure or none at all. Here and there the microscopist may imagine that he recognizes the brown sacks, but in the last analysis there is no positive proof of them. If conclusions were to be based upon the structure of the bodies in this coal alone, they would be relegated at once to the category of the unknown; but in looking over the bogheads from different places and considering the varying state of preservation of the structure, a continuous series can be constructed—at one end those in which the structure is perfectly preserved, gradually and imperceptibly grading into those at the other end, in which no structure is observable, the same or very similar general form, color, and nature being maintained throughout the series. Such a result gives strong support to the reasoning that the whole series is of the same origin. Such a series comprises the Australian bogheads, with the structure in a perfect state of preservation, at one end, and the Pennsylvanian bogheads, with no structure preserved, at the other. In this light, until further evidence is found to the contrary, it may be assumed that the deposit at Kiskiminetas Junction is of the oil-algal origin and a true boghead coal.

CANNEL COAL FROM UPPER POTTSVILLE FORMATIONS IN WESTERN PENNSYLVANIA AND EASTERN KENTUCKY.

Samples of cannel coal from the upper Pottsville at Lesley, near Paintsville, Ky., were also examined. The bed at Lesley is approximately 5 feet 9 inches thick. At the bottom is a layer of ordinary bituminous coal about 2½ inches thick, changing soon into cannel coal, which continues to the top, with the exception of a 4-inch layer of stratified bituminous coal in the middle of the bed. The bed has a roof of rather gritty gray shale containing carbonized plant remnants and residues.

The cannel is black and tough and cleaves in slabs of varying thickness; but the cross and oblique fractures are distinctly conchoidal. The cannel is really a spore cannel coal, because by far the larger part of the organic matter consists of spore matter. Spore exines of a number of different kinds, both microspores and megaspores, enter into its composition. Much macerated spore matter and some cuticular matter are observed in the ground mass.[36]

Among the spore exines are peculiar yellow bodies in varying amounts, resembling those of the boghead coals in certain respects. No definite organized structure, however, can be discerned in them. These bodies have been described by the writer[36] as follows:

> The coal contains interesting objects that are very abundant in certain strata, where they constitute more

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[36] White, David, and Thiessen, Reinhardt, The origin of coal: Bur. Mines Bull. 38, p. 253, 1914.

than half of the bulk. In other strata they are comparatively rare. On the whole, they constitute only a small proportion of the total mass. They are in general appearance distinctly similar to Renault's genus *Pila* of his supposed algae.

These bodies vary greatly in size, ranging roughly from 30 to 175 microns in diameter. In color they are almost of a paraffin-white, which in thicker sections becomes a light brass-yellow. Their form is roughly oval, with an irregular outline. This irregularity consists of processes, often pseudapoda-like, and irregular cavities or depressions, reaching often to the center or even through the body.

The structure of these bodies is, in fact, so irregular that an adequate description of it is difficult. It is probable that these yellow bodies had their origin in an organism similar to that which gave rise to the Australian and European boghead coals.

Numerous yellow bodies, apparently comparable to those described in the foregoing pages, are found in a cannel coal occurring in the Mercer shale on Neshannock Creek near Leesburg, in Springfield Township, Mercer County, Pa. As shown in Plate XL, *B*, this coal contains much material of humic origin. Besides the spore exines and the yellow bodies, of which the latter are plainly recognizable in the photograph, the section discloses large numbers of cuticular fragments and numerous lumps of resin, two kinds of which, one dark and the other lighter, are seen on the left.

It is likely that a close examination of cannel coals will reveal algal colonies in many of them, as is to be expected on account of the open-water environment in which they were laid down. In view of the interesting results of the present study of bogheads and cannel coals, a more systematic examination of the cannel series, of which abundant material is already in hand, is contemplated.

SUMMARY.

According to origin, bituminous shales and cannel coals may be classified into humic, spore, ceric, resinous, and algal deposits.

This paper endeavors to show that the yellow bodies of the boghead coals are not derived from spores but represent colonies of alga-like organisms heretofore not well known. In all the bogheads investigated these colonies, described as *Reinschia* and *Pila*, are similar to an organism now living in the salt lakes and salt lagoons of South Australia and neighboring islands. The living organism has been termed *Elaeophyton* because of the large amount of oil it contains.

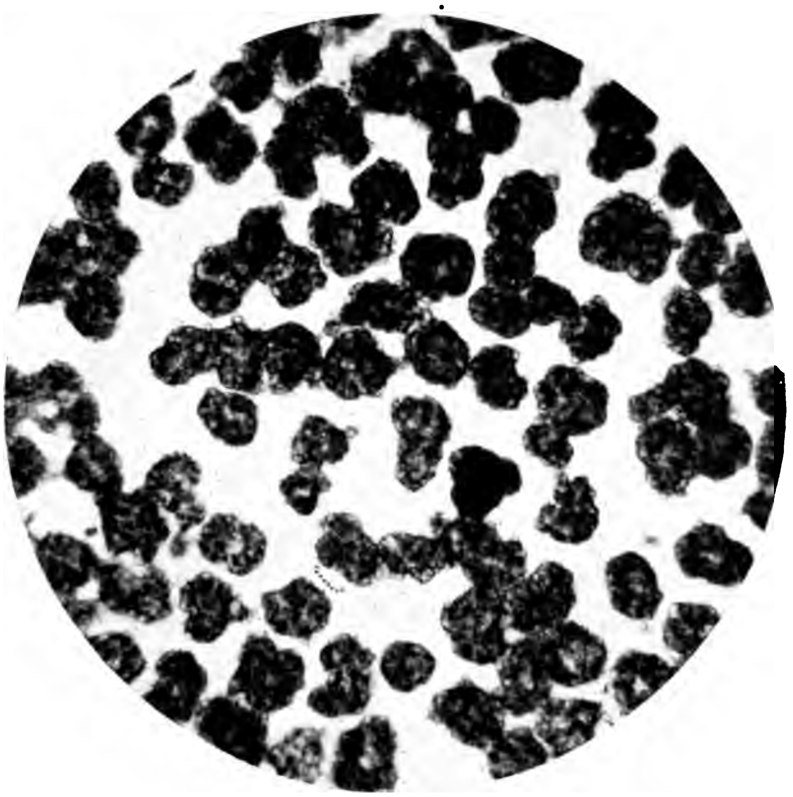
Elaeophyton is a colonial organism in some respects resembling some of the blue-green algae, but its cell wall differs from that of the algae ordinarily described. The colonies, which are just visible to the naked eye, may be single or compound; they are solid and of globular form. Each colony is composed of an irregular outer zone of living cells, several cells deep, inclosing a core of irregular inner cells that lack protoplasmic contents. The living cell contents are of oval or ovoid form, are relatively small (about 3 microns in diameter and 5 microns long), and contain no definite nuclei. They are surrounded by a relatively thick cell wall of irregular thickness. The different cells are cemented together by a medium apparently similar to the cell walls. These colonies appear on the lakes and lagoons toward the end of winter, are blown to the shore, and there form a rubber-like mass called coorongite. Coorongite does not appear to decompose or oxidize further; it is rich in oil and volatile matter, burns with a bright, hot flame, and melts before burning. When heated in a closed test tube it melts into a sirupy liquid, becoming viscous on cooling. When distilled, it yields about 70 per cent of oils, some tarry matter, some gas, and very little solid residue. Coorongite is the peat stage of boghead coal.

The structure and size of the yellow bodies in the boghead coals examined correspond closely to those of the colonies of *Elaeophyton*. The yellow bodies contain an outer zone of thick-walled cells inclosing oval sacks, most of which have brown contents. These sacks represent the once living protoplasmic contents of the cell. The preservation of the structure as a whole differs in deposits at different localities, the coals examined showing a range from a very well preserved structure to a condition in which the structure has been completely effaced. A similar range occurs to some extent in the deposits of well-preserved material. By analogy and through the similarity in structure, appearance, and qualities of the yellow bodies in the boghead series, it is concluded that all had a similar source—that is, colonial algae of the same general nature and of a composition similar to that of the colonies of the living *Elaeophyton*.

ACKNOWLEDGMENTS.

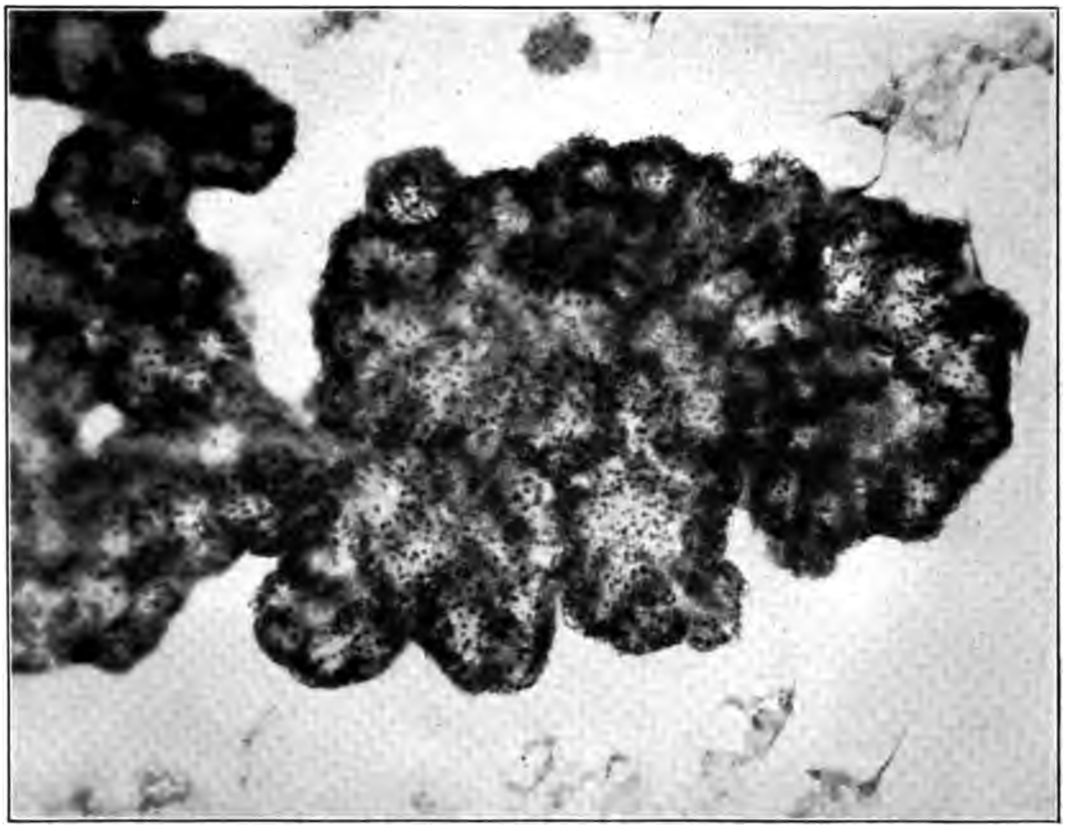
In addition to numerous suggestions made by members of the Bureau of Mines staff, whose names need not be mentioned, the writer is indebted for extensive and constructive criticism to David White, most of whose suggestions have been incorporated in these notes.

PLATES XXVII—XL



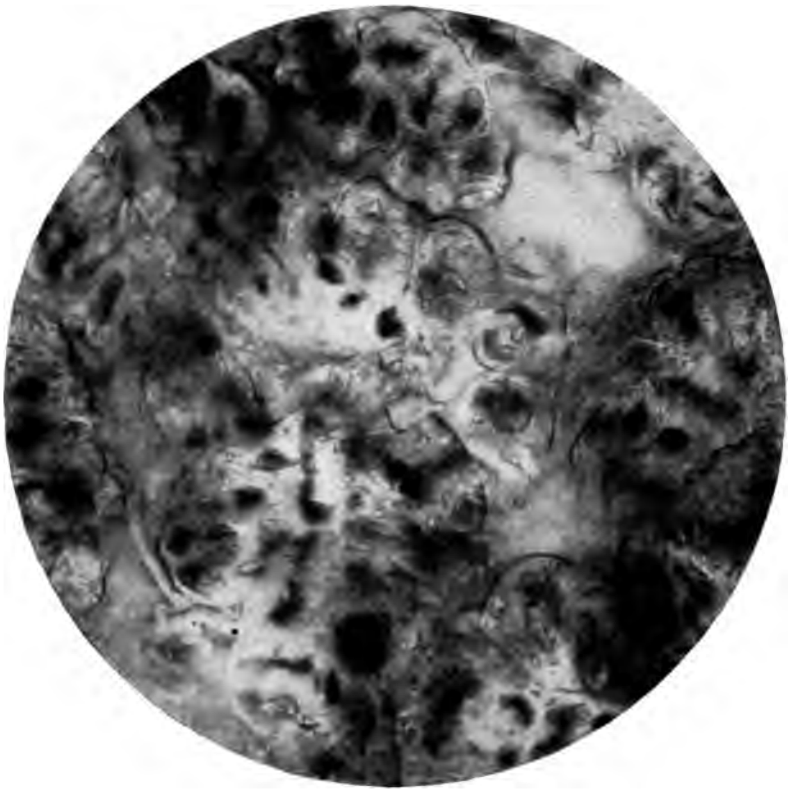
A. COLONIES OF THE LIVING ONE-CELLED ALGA, ELAEOPHYTON N. GEN., FROM THE COORONG DISTRICT, SOUTH AUSTRALIA

Single as well as compound colonies are shown. The size of the compound colonies depends on the number of primary colonies in them. The small bodies are apt to be single colonies, the larger ones compound colonies. × 200



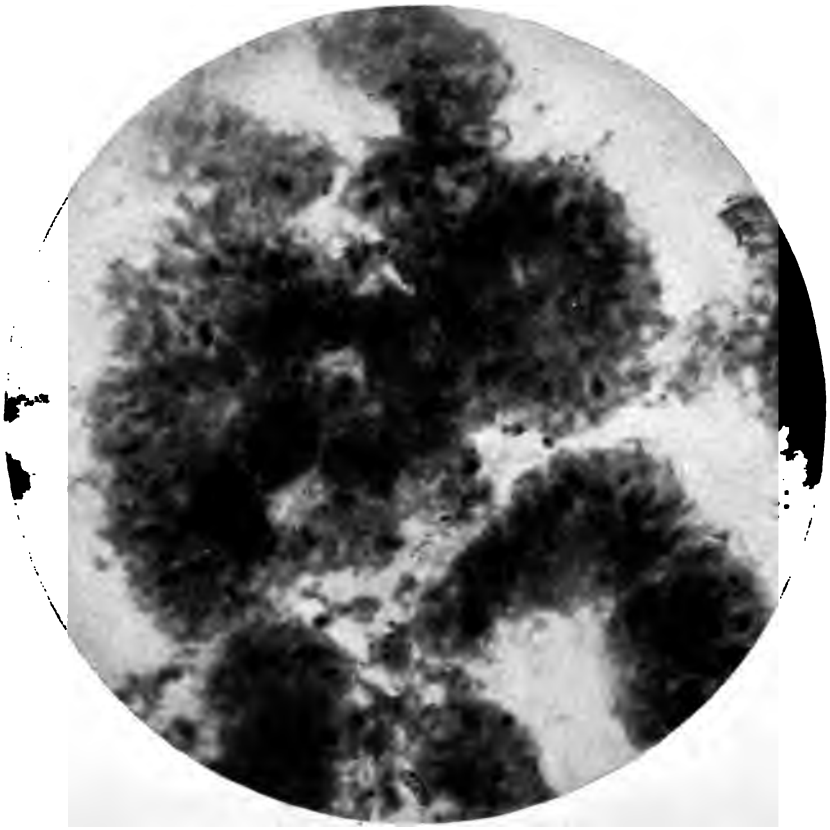
B. A NUMBER OF COLONIES OF ELAEOPHYTON MERGING INTO A LARGER MASS

The black specks represent the living cell contents. × 200

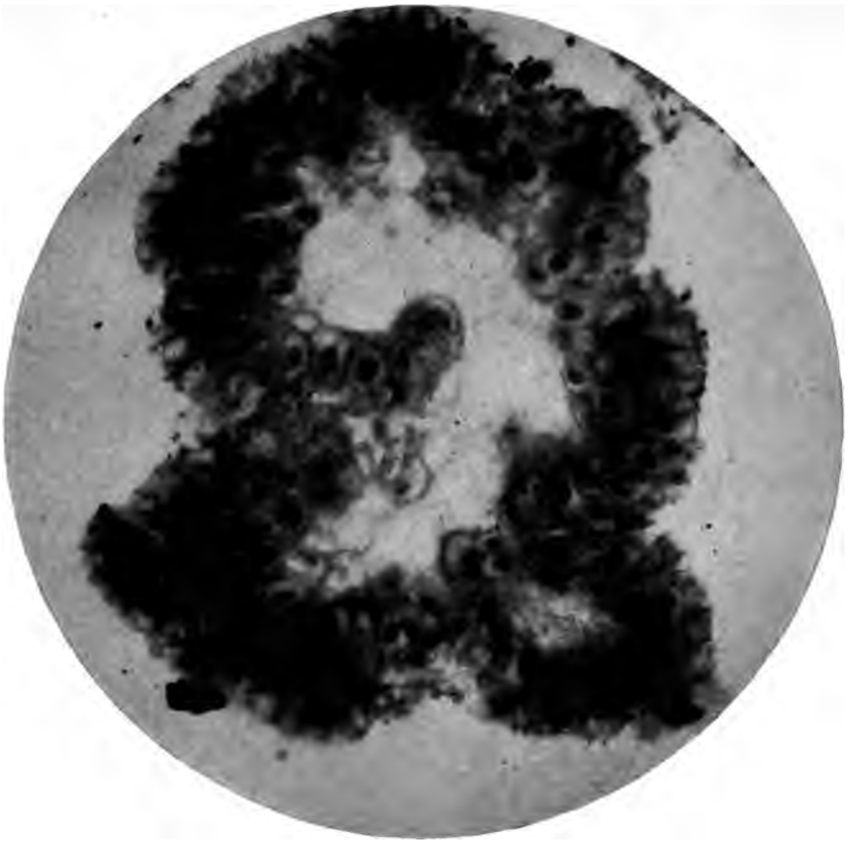


A. A COLONY OF THE LIVING ELAEOPHYTON, COMPRESSED UNDER THE COVER GLASS AFTER STAINING WITH SAFRANIN

The dark oval or ovoid spots represent the living cell contents. At many points the outlines of the cell walls are shown. × 1,000

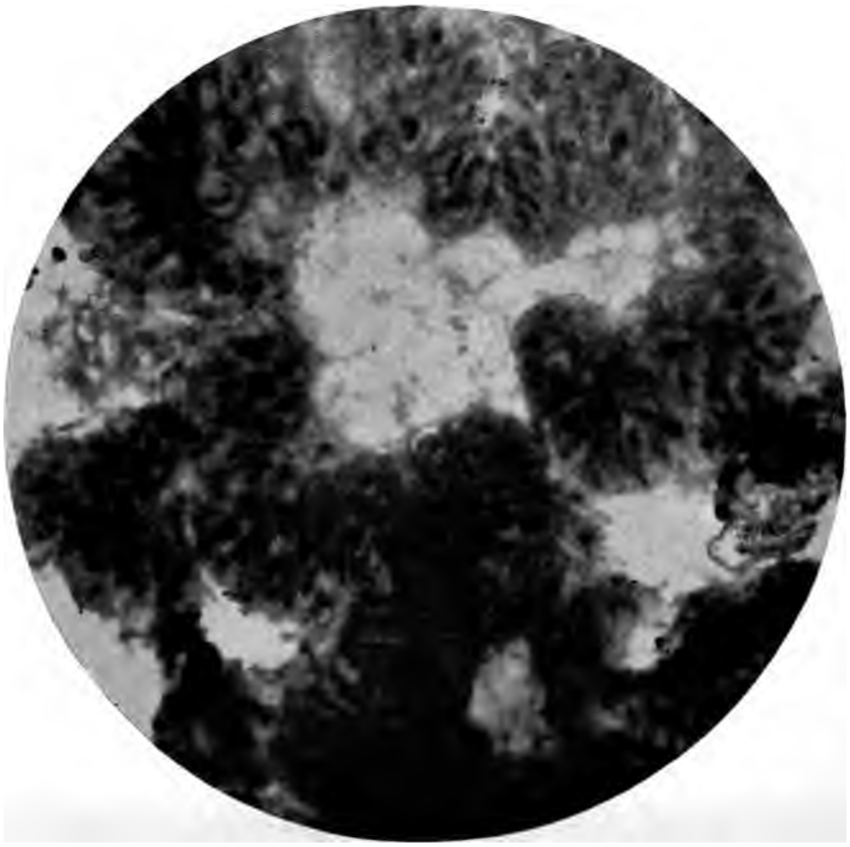


B. SECTIONS OF SEVERAL COLONIES OF ELAEOPHYTON, TWO OF WHICH SHOW THE CORE OF INNER BLANK CELLS. × 600



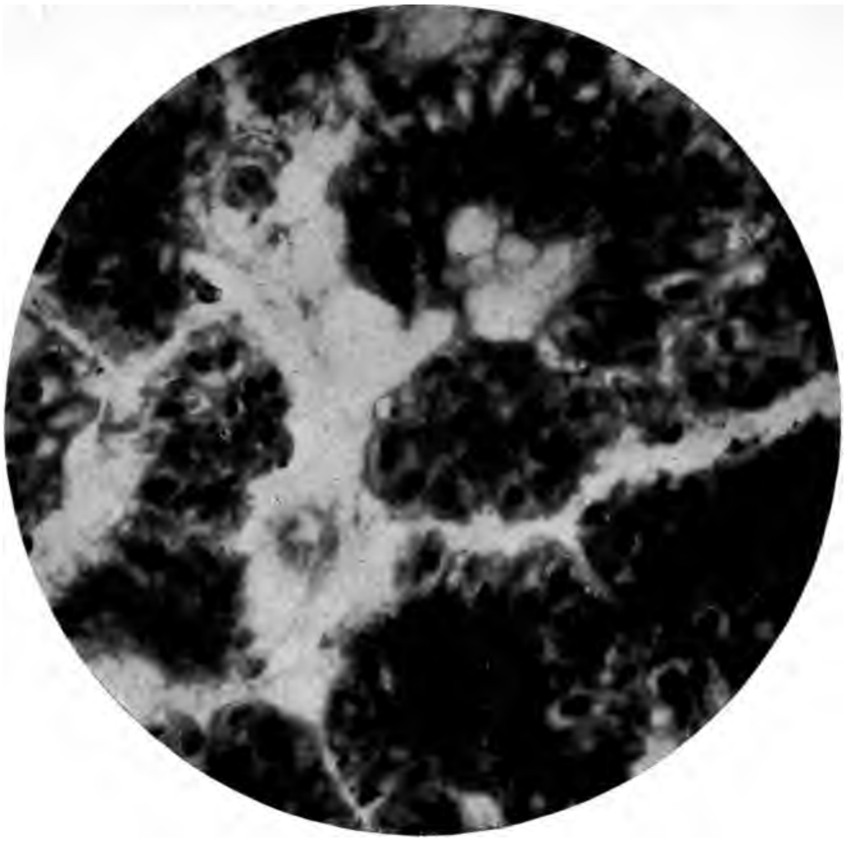
A. SECTION OF A SMALL COMPOUND COLONY OF ELAEOPHYTON

Showing the thick zone or shell of living cells, and the structure of the inner core of blank cells. × 600



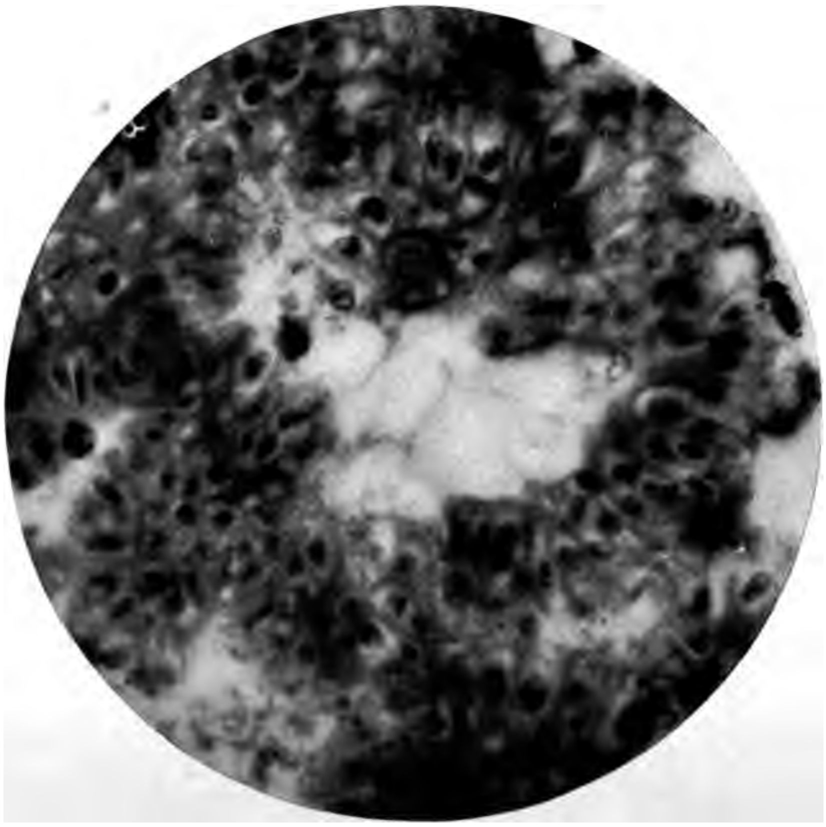
B. SECTION OF COMPOUND COLONY OF ELAEOPHYTON AND OF AN ADJOINING SINGLE COLONY

Showing the blank inner tissue surrounded by an outer zone of living cells. × 600



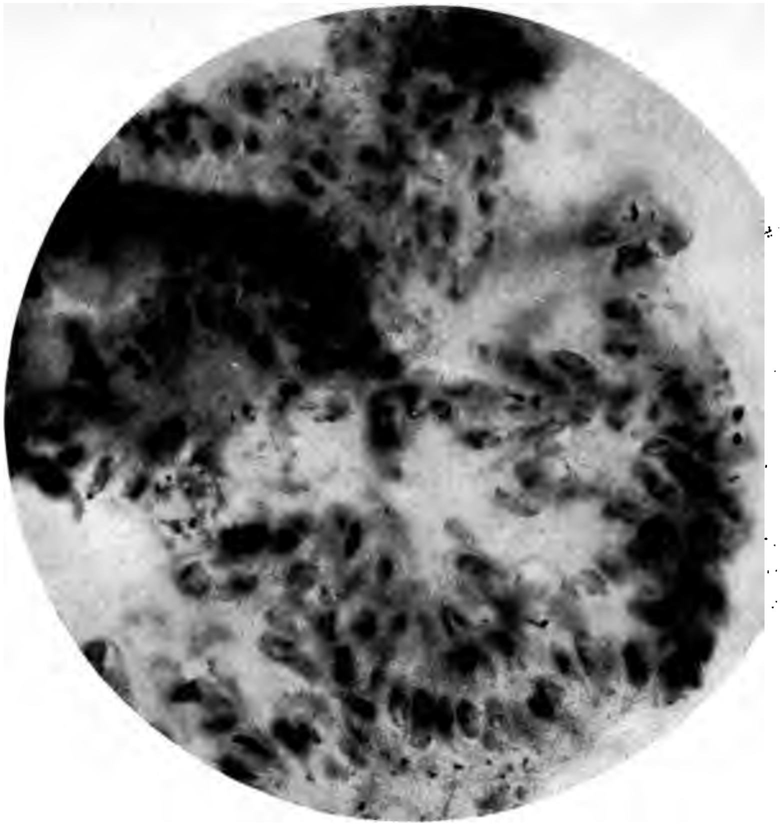
A. SECTION OF COMPOUND COLONY OF ELAEOPHYTON AND PARTS OF NEAR-BY COLONIES AT A HIGHER MAGNIFICATION

Plates XXX and XXXI show more definitely the organization of the individual cells. The oval dark spots represent the contents of the living cell, the lighter area bordering each of these spots represents the reinforcement of fatty or oily matter deposited inward on the primary cell wall, and the darker heavy lines surrounding the cells and uniting them represent the cementing matter. The lighter areas of irregular structural pattern represent the blank cells. The irregular light strips represent open spaces between the colonies. × 1,000



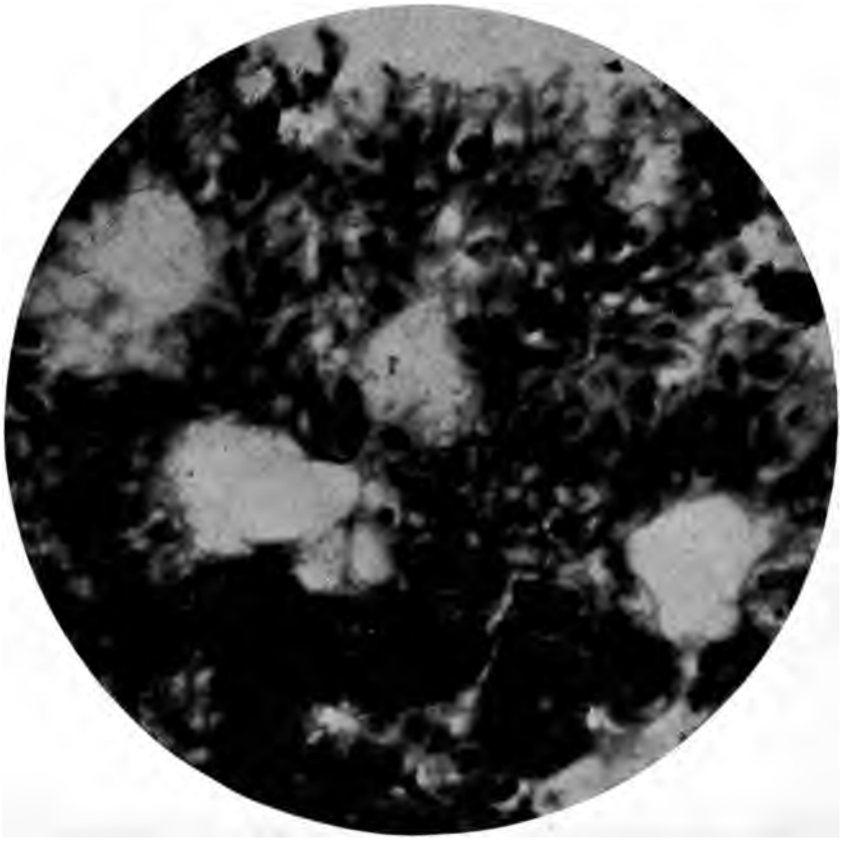
B. SECTION OF COMPOUND COLONY OF ELAEOPHYTON

Showing in particular the aspect and variation of the blank cells in the center of the colony. × 1,000



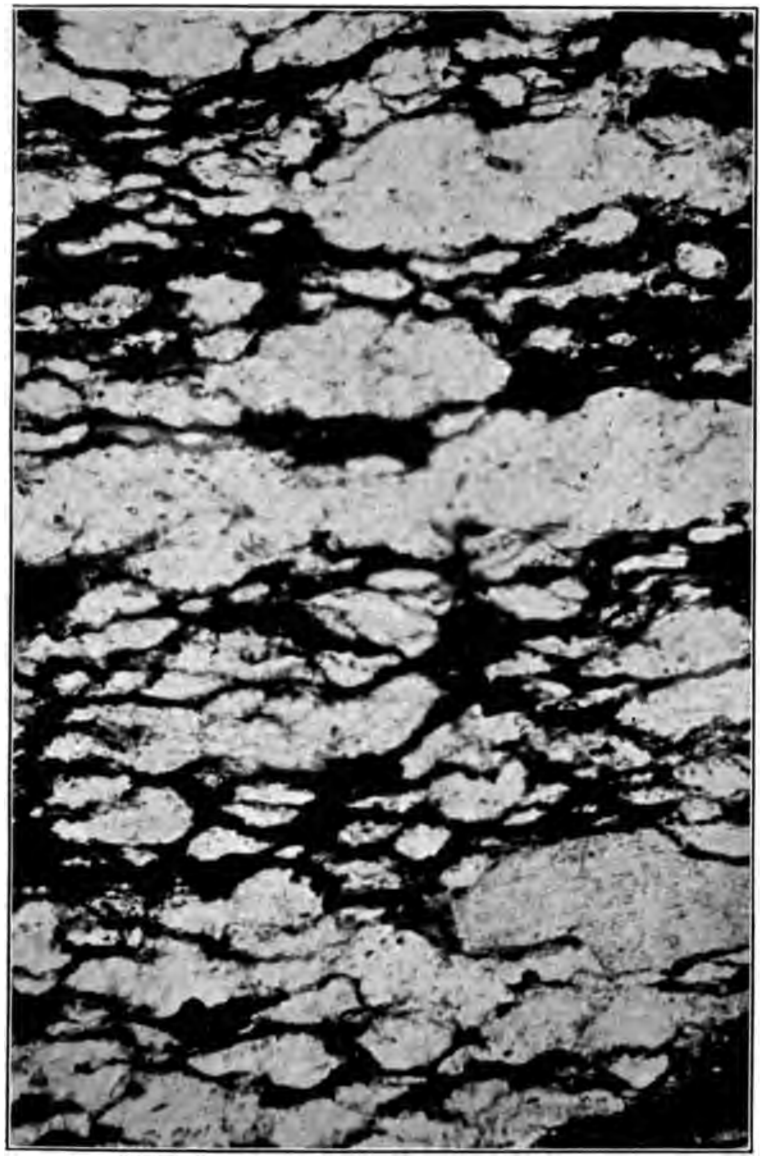
A. SECTION OF COMPOUND COLONY OF ELAEOPHYTON

Showing the thick fatty matter deposited about the cavity of the cell and forming its thick wall. Compare this figure with Plate XXXIV, *A.* × 1,000



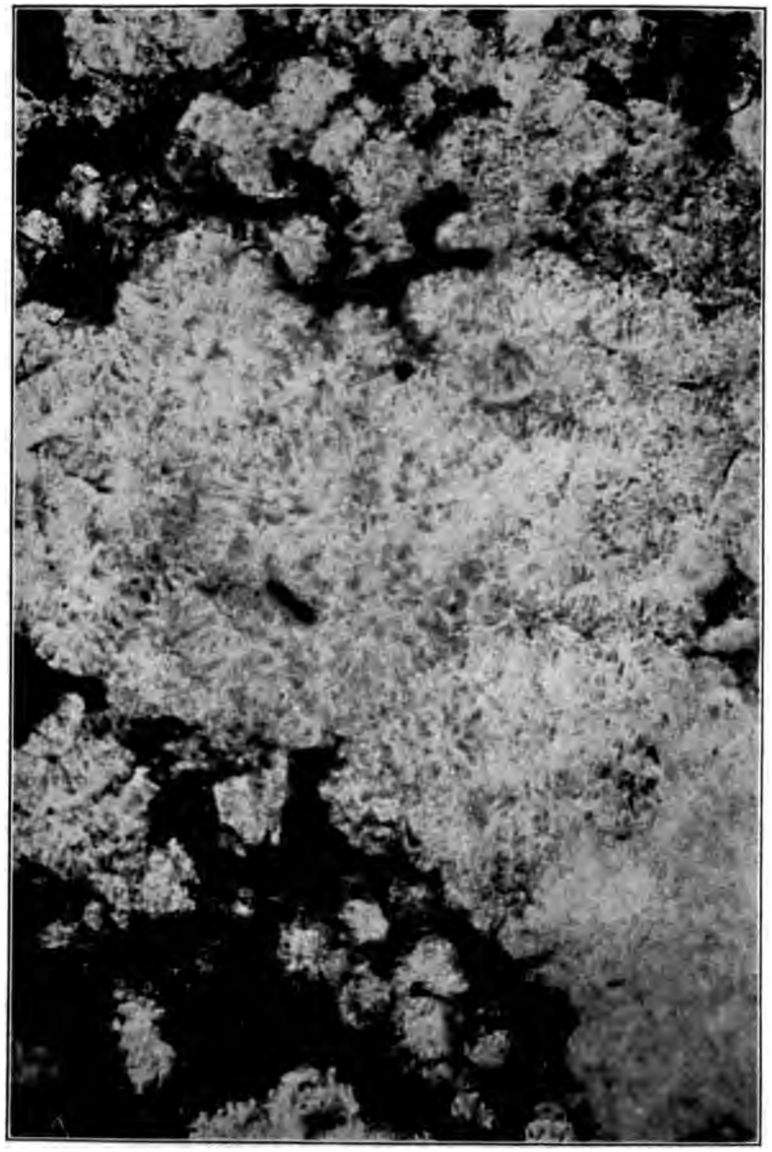
B. SECTION OF COMPOUND COLONY OF ELAEOPHYTON

Showing variability in size, form, and aspect of blank cells; also relations of fatty inner cell thickening about the central cavity to the cementing matter and the blank cells. × 1,000



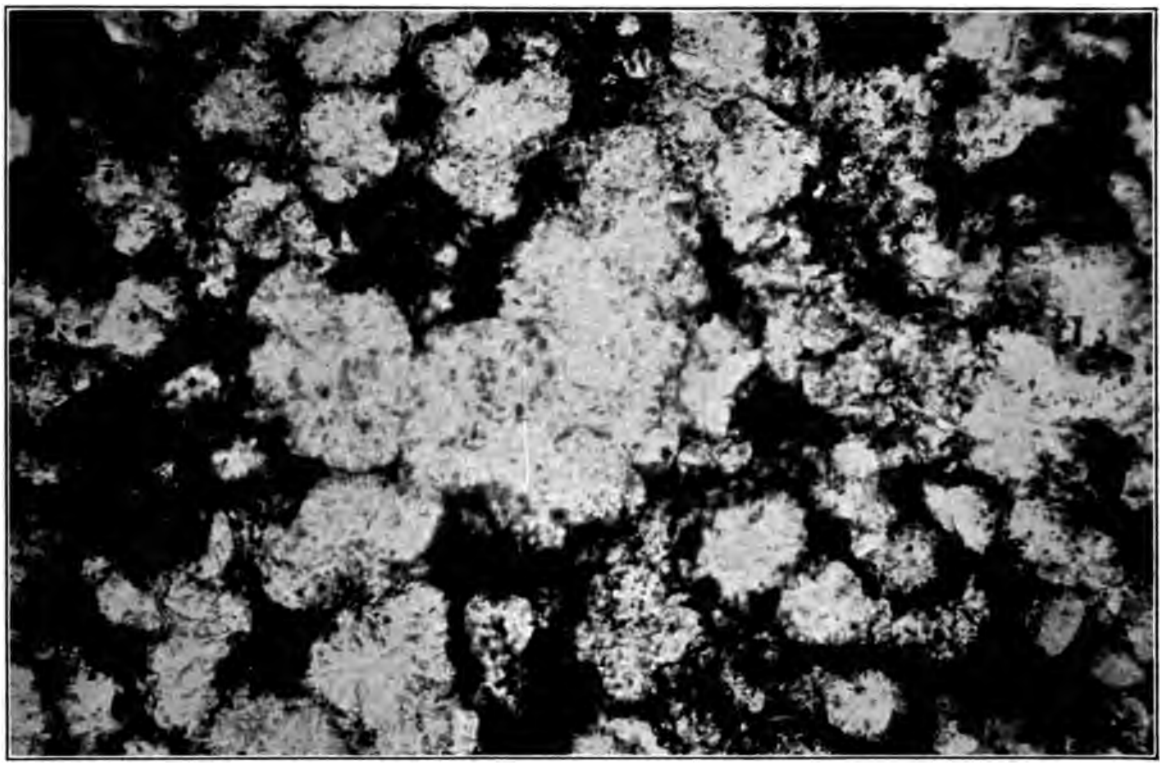
A. CROSS SECTION OF BOGHEAD COAL (THE SO-CALLED KEROSENE SHALE) OF PERMIAN AGE FROM THE WOLGAN VALLEY, NEWNES, NEW SOUTH WALES, AUSTRALIA

The irregular, light, somewhat spongy masses that form "yellow bodies" in this fossil deposit are the compound colonies of the one-celled alga Reinschia australis B. Renault. × 200



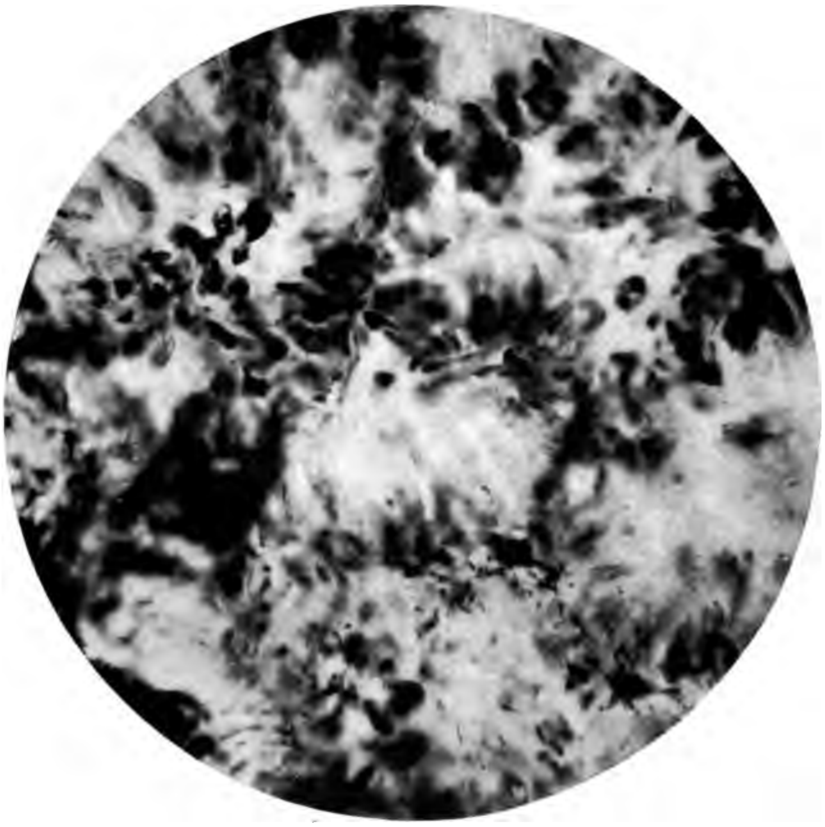
B. HORIZONTAL SECTION OF BOGHEAD COAL OF PERMIAN AGE FROM THE WOLGAN VALLEY, NEWNES, NEW SOUTH WALES

The section shows large and small colonies of Reinschia australis B. Renault. × 200



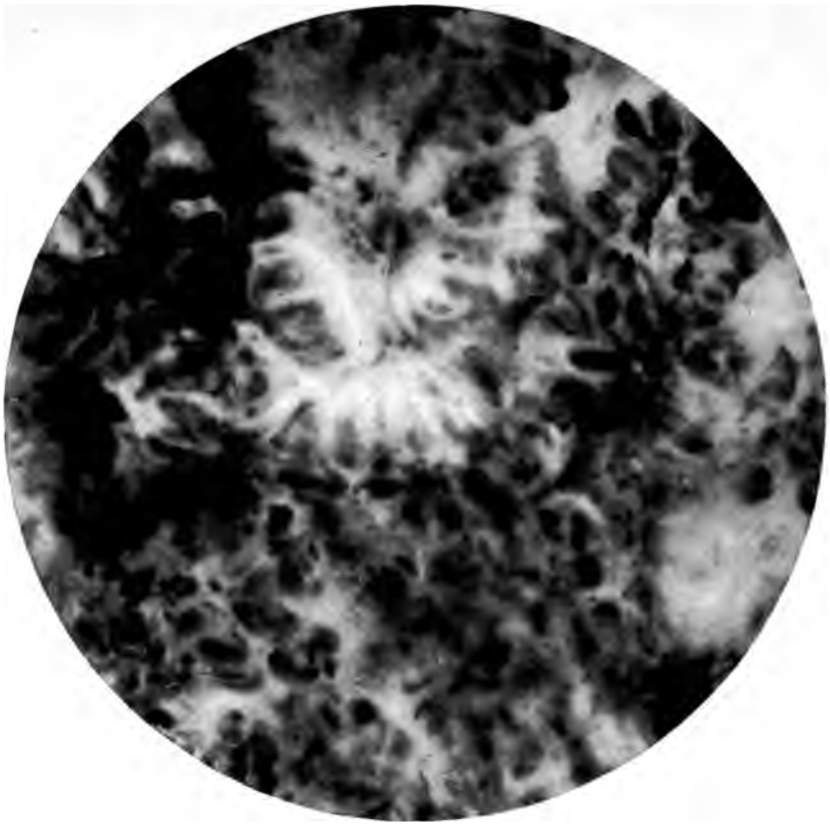
A. HORIZONTAL SECTION OF BOGHEAD COAL OF PERMIAN AGE FROM THE WOLGAN VALLEY, NEWNES, NEW SOUTH WALES, AUSTRALIA

This section shows compound colonies, mostly of rather small size, of the fossil alga Reinschia australis B. Renault. × 200



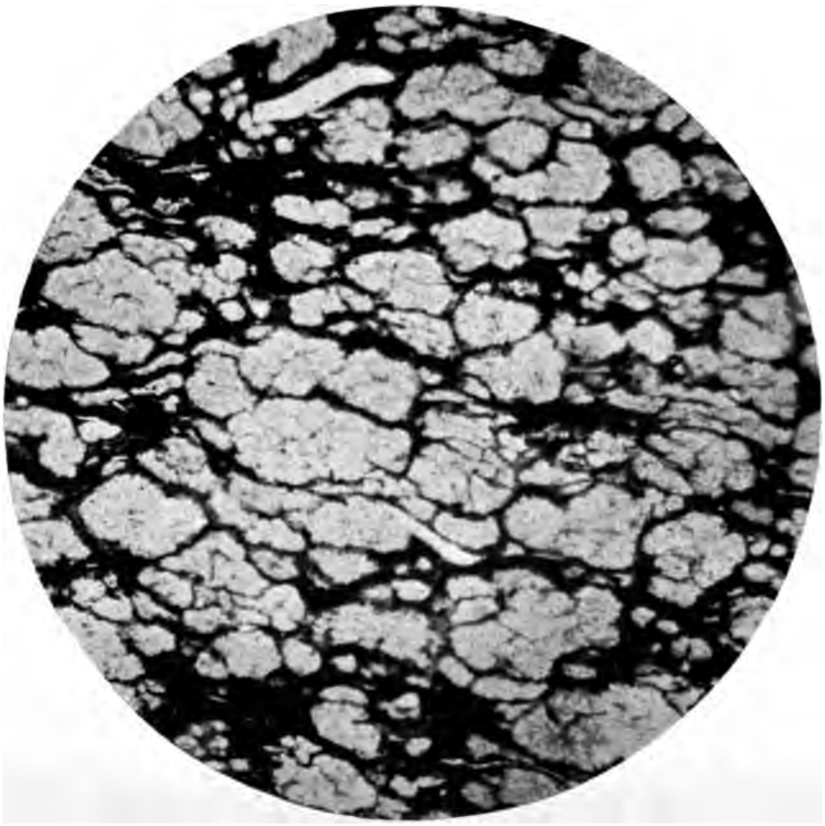
B. HORIZONTAL SECTION OF BOGHEAD COAL OF PERMIAN AGE FROM THE WOLGAN VALLEY, NEWNES, NEW SOUTH WALES, AUSTRALIA

More highly magnified to show a number of primary colonies of the fossil alga Reinschia australis B. Renault. The dark oblong spots represent the remains of the contents of the living cells, now stained dark by biochemical decomposition products more or less distinctly humic. × 1,000



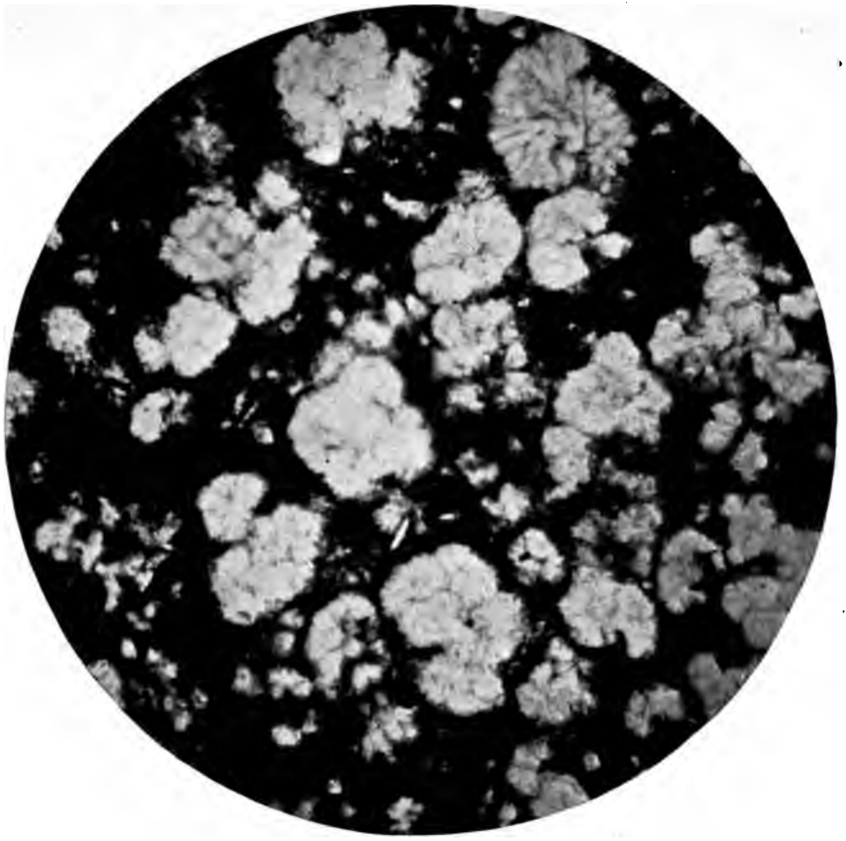
A. HORIZONTAL SECTION OF BOGHEAD COAL OF PERMIAN AGE FROM THE WOLGAN VALLEY, NEWNES, NEW SOUTH WALES, AUSTRALIA

Showing colonies varying in size of the fossil alga Reinschia australis B. Renault, characteristic of the kerosene shale. The more completely the rock is made up of these colonies of fatty algæ the more voluminous the distillate and the better its quality. × 1,000



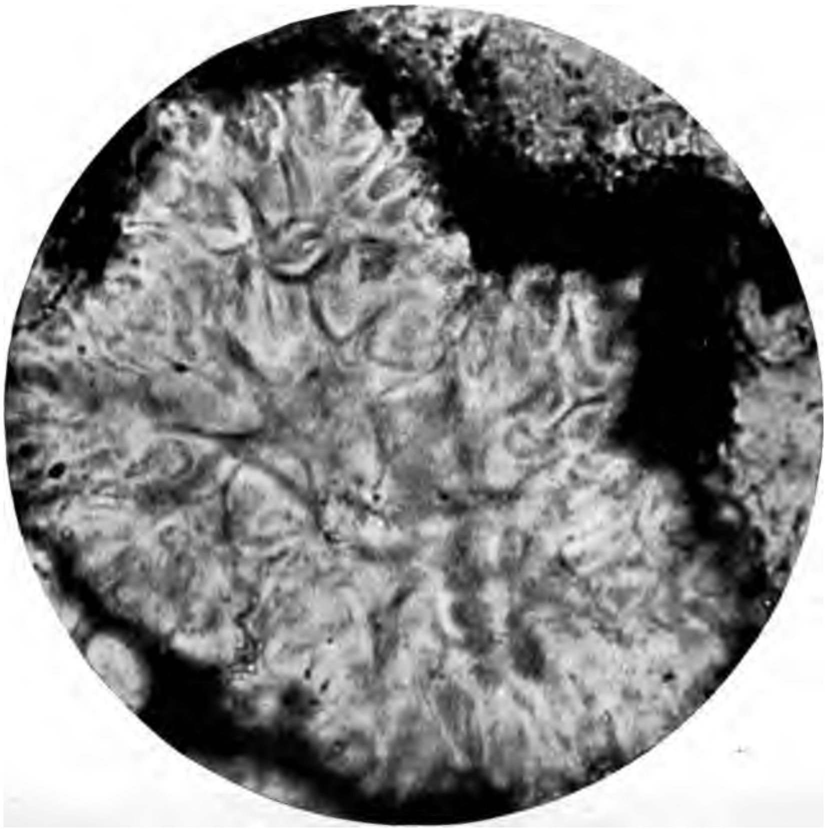
B. CROSS SECTION OF BOGHEAD COAL (TORBANITE) OF MISSISSIPPIAN AGE FROM TORBANE HILL, SCOTLAND

The section shows the colonies of the one-celled alga Pila scotica B. Renault, now fossil and embedded in a general attritus of dark-brown color. But little flattening has taken place. × 200



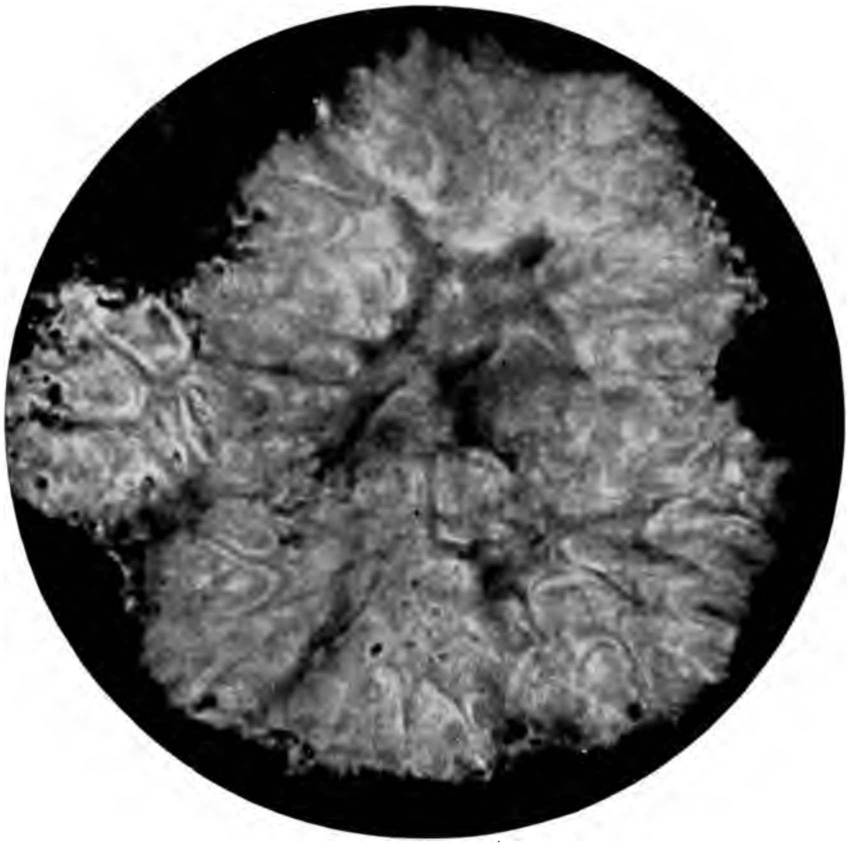
A. HORIZONTAL SECTION OF BOGHEAD COAL (TORBANITE) OF MISSISSIPPIAN AGE FROM TORBANE HILL, SCOTLAND

The colonies of the fossil one-celled alga Pila scotica B. Renault, which form the "yellow bodies," are embedded in an attrital matrix of dark-brown color, "the groundmass," in which is mingled a considerable amount of dirt. The large macerated body at the top appears to represent the fossil organism described by B. Renault as Cladiscothallus, a fungus. × 200



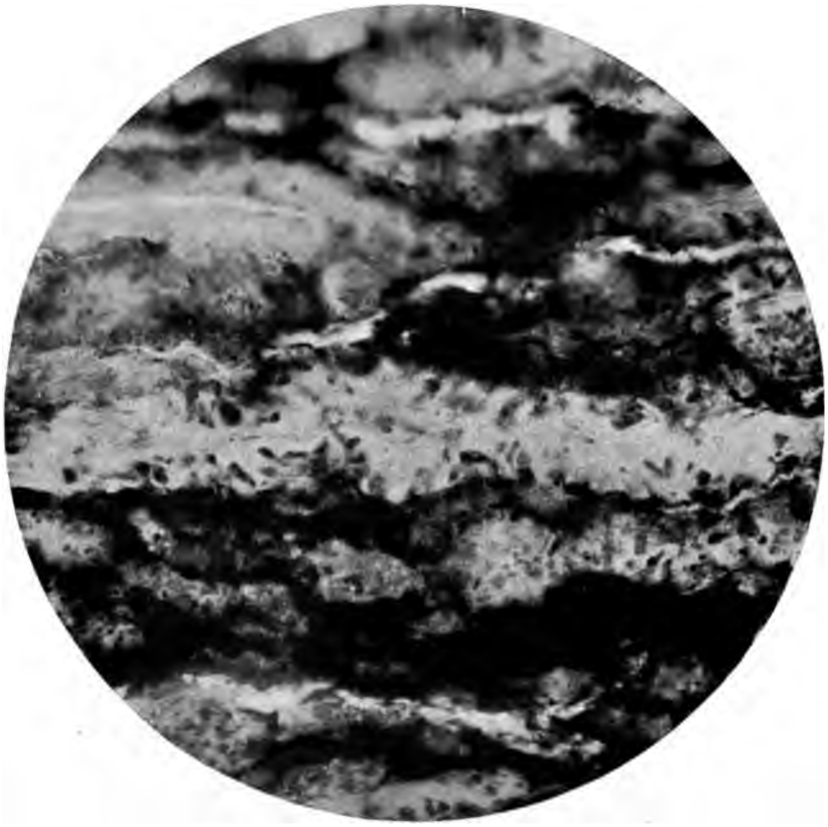
B. HORIZONTAL SECTION OF A COLONY OF PILA SCOTICA B. RENAULT FROM THE SAME LOCALITY AND DEPOSIT AS THE SPECIMEN ILLUSTRATED IN *A*

Shows an outer zone of cells surrounding the inner core of blank cells in the fossil species just as in the living Elaeophyton. The brown cell contents of some of the cells are distinguishable. The algae of the colonies are slightly decomposed around the edges of the colonies. × 1,000



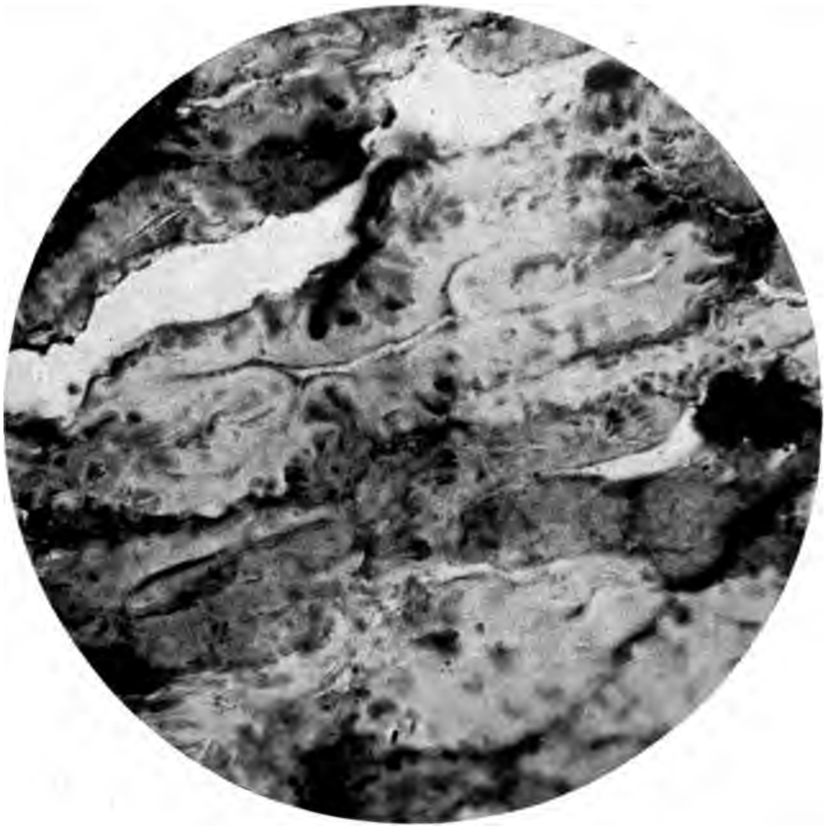
A. HORIZONTAL SECTION OF AN ALGA COLONY, PILA SCOTICA B. RENAULT, IN THE BOGHEAD COAL (TORBANITE) OF MISSISSIPPIAN AGE FROM TORBANE HILL, SCOTLAND

The primary colonies are easily distinguishable; also the inner core of blank cells. The brown oval contents of the cells have largely disappeared, as is common in this boghead coal, but the outlines of the cells are still visible through a difference in refraction. × 1,000



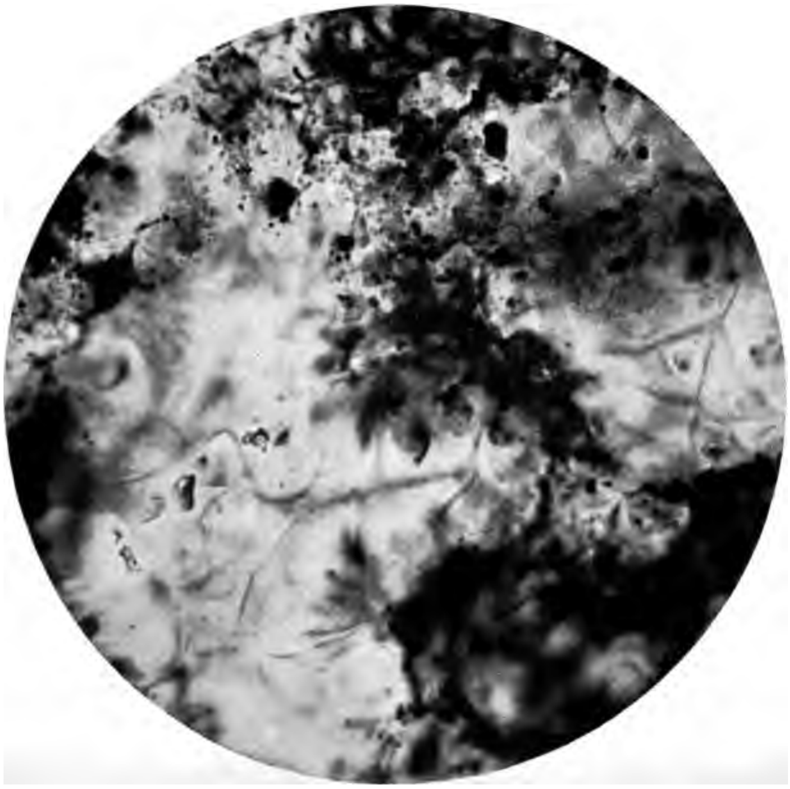
B. CROSS SECTION OF BOGHEAD COAL OF MISSISSIPPIAN AGE FROM BATHGATE, SCOTLAND

The "yellow bodies," compound colonies of the one-celled alga Pila scotica B. Renault, have been much more flattened than are those in the deposit at Torbane Hill. (See Pl. XXXV.) The blank cells of the core of the colony have been more flattened than the individual algae, thus giving the colony the appearance of a highly sculptured spore exine. × 1,000



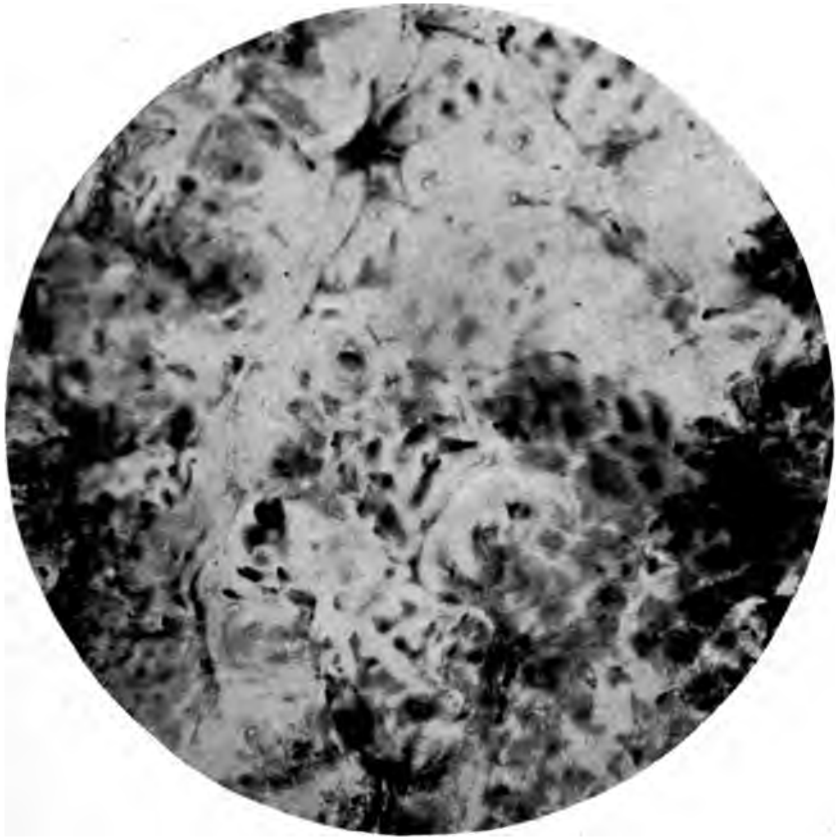
A. CROSS SECTION OF BOGHEAD COAL OF MISSISSIPPIAN AGE FROM BATHGATE, SCOTLAND

The "yellow body" in the central part of the photograph is clearly shown to be a compound colony of the one-celled fossil alga Pila scotica B. Renault. The primary colonies are well marked off. × 1,000



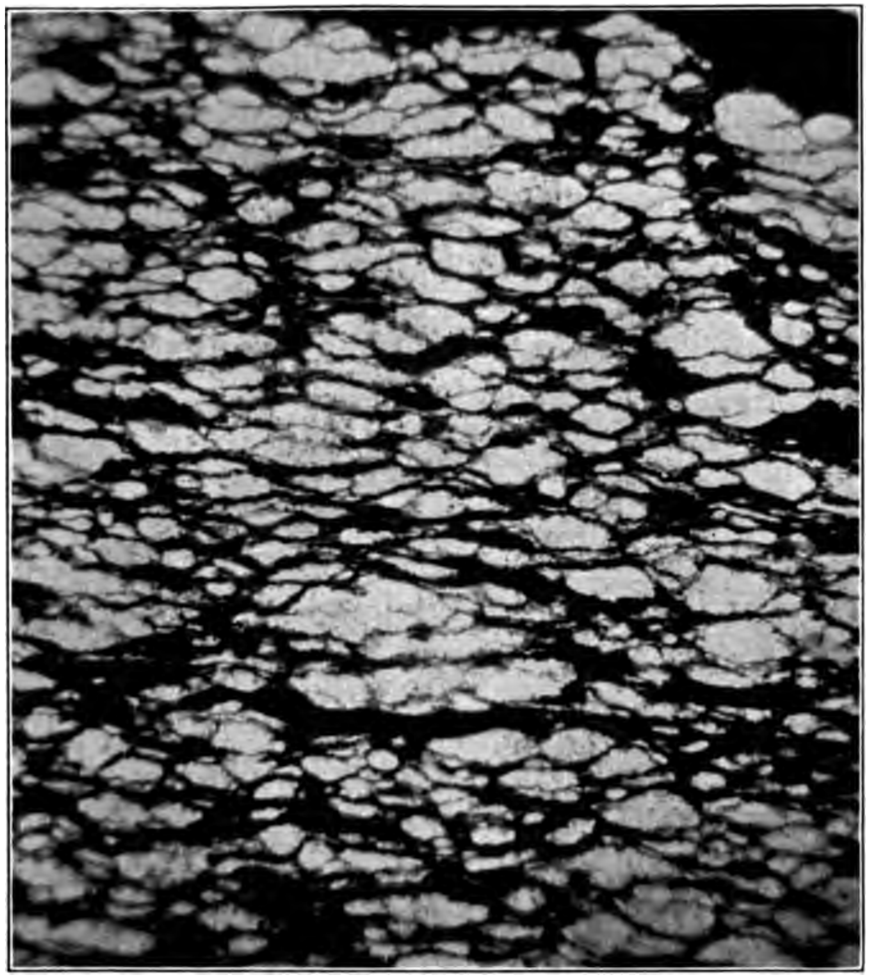
B. HORIZONTAL SECTION OF BOGHEAD COAL OF MISSISSIPPIAN AGE FROM BATHGATE, SCOTLAND

The outlines of the cells of the individual algae (Pila scotica B. Renault) in this highly magnified thin section are rather clearly shown, and the brown oval cavity which once contained the protoplasm of the alga is shown distinctly. × 1,000



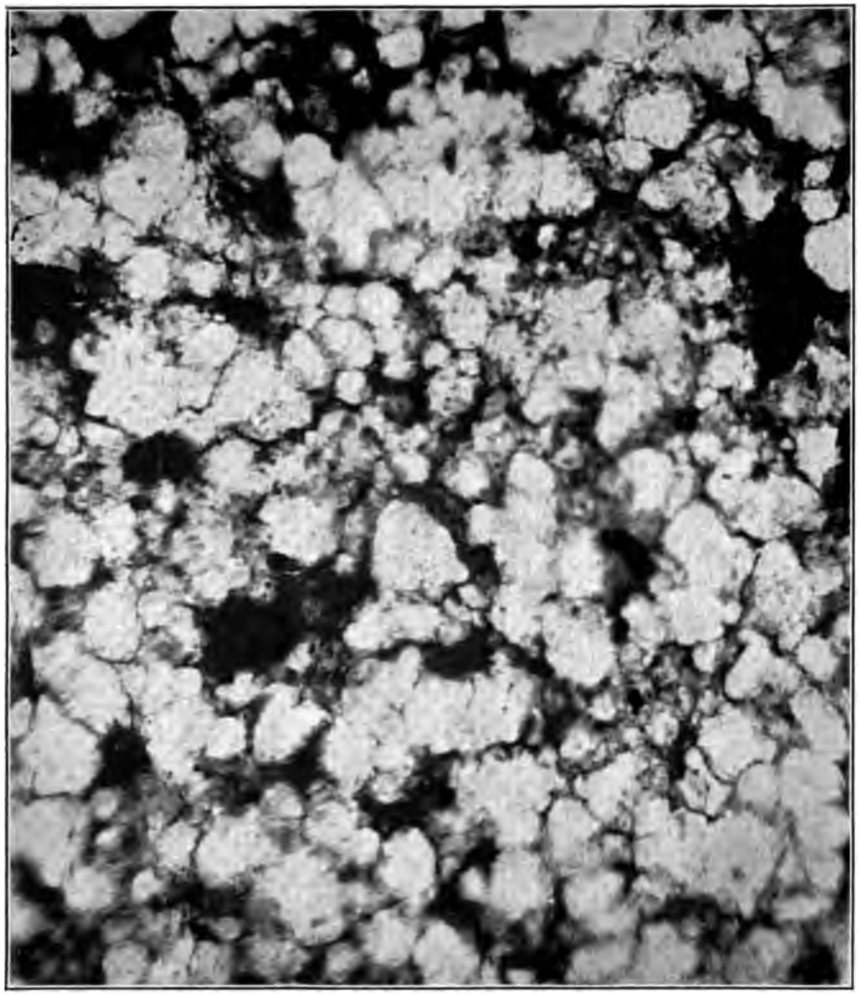
A. HORIZONTAL SECTION OF BOGHEAD COAL OF MISSISSIPPIAN AGE FROM BATHGATE, SCOTLAND

This section outlines the primary colonies of the oil-forming fossil alga Pila scotica B. Renault, and the brown cell contents are clearly distinguishable. This and the four preceding illustrations should be compared with the photographs of the living Elaeophyton shown in Plates XXIX, XXX, and XXXI. × 1,000



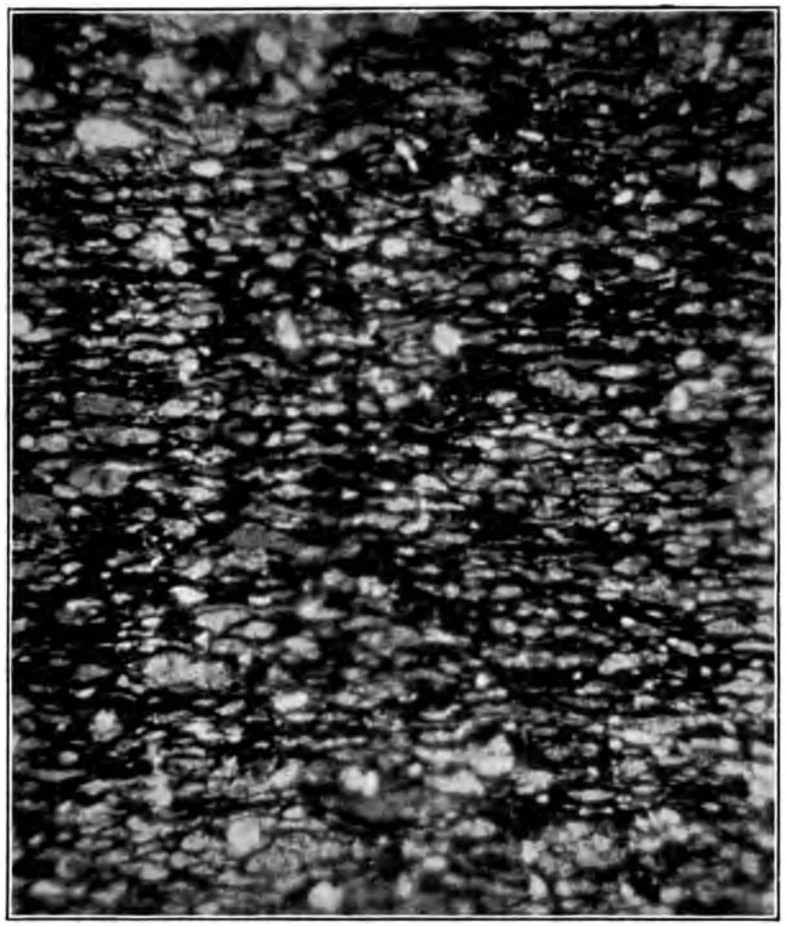
B. CROSS SECTION OF A BOGHEAD COAL FROM COLVILLE RIVER, ALASKA, SHOWING YELLOW BODIES

The obscurely indicated structure is comparable to that of the living Elaeophyton and to the fossil alga colonies characteristic of the kerosene shale (torbinate) and other bogheads. The Alaska yellow bodies also are probably compound colonies of a related alga. X 209



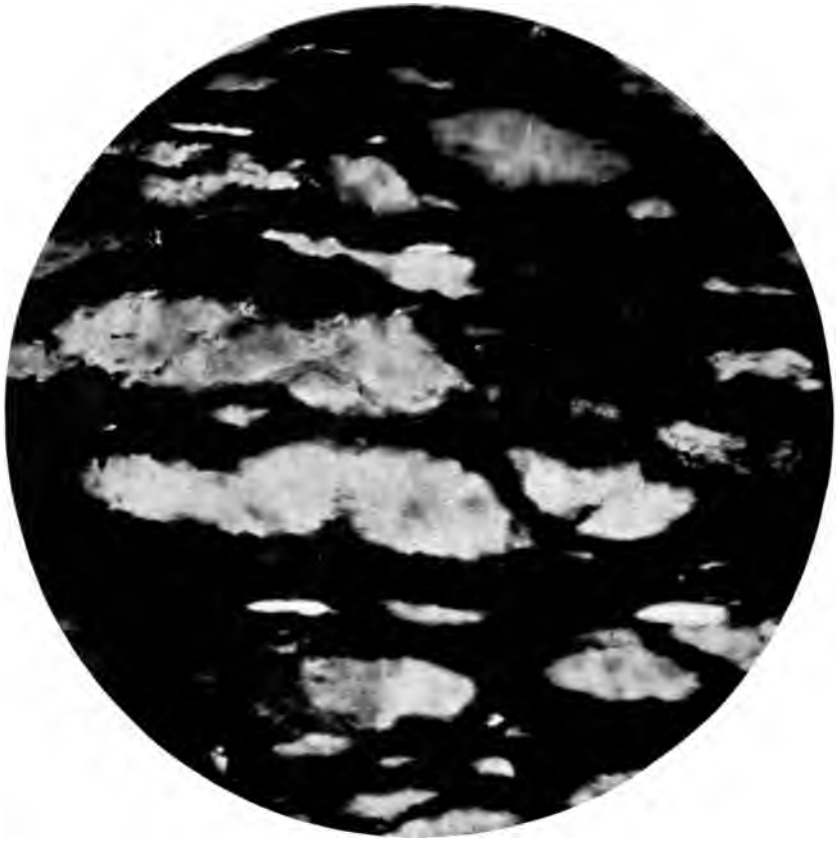
A. HORIZONTAL SECTION OF BOGHEAD COAL FROM COLVILLE RIVER, ALASKA

The similarity between the yellow bodies in this fossil deposit of unknown age in Alaska to the compound colonies of Elaeophyton (see Pl. XXVII) and to the fossil boghead algae of different ages is at once apparent. × 200



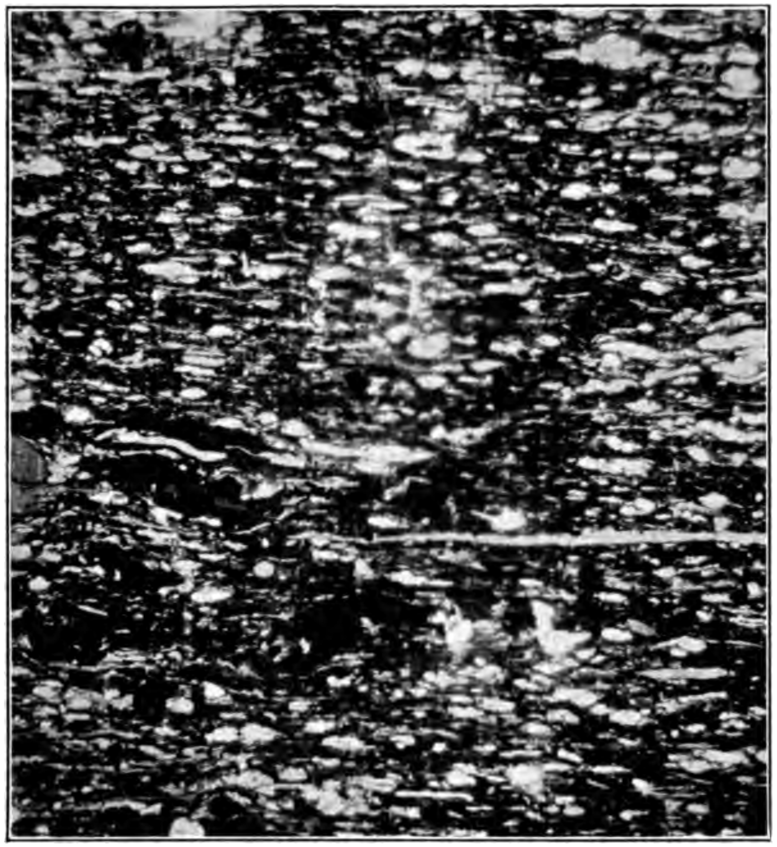
B. VERTICAL SECTION OF BOGHEAD COAL, LYING MIDWAY BETWEEN THE UPPER AND LOWER FREEPORT COALS, IN THE ALLEGHENY FORMATION AT KISKIMINETAS JUNCTION, WESTMORELAND COUNTY, PA.

The organic matter in this deposit is composed very largely of yellow bodies, apparently comprising algal colonies closely comparable in general aspect and to a degree at least in structure with Elaeophyton and the fossil types of boghead colonial algae. Relatively very few spores are present. The deposit begins with an ordinary shale at the bottom, which first gradually and then quickly changes into a rich boghead coal. × 200



A. CROSS (VERTICAL) SECTION OF CANNEL COAL FROM A FREEPORT BED OF THE ALLEGHENY FORMATION AT KISKIMINETAS JUNCTION, WESTMORELAND COUNTY, PA.

The yellow bodies in this section, here seen in greater enlargement, are strongly suggestive of Elaeophyton and are probably alga colonies similar in general composition to the living and the fossil forms shown in the preceding illustrations. × 1,000



B. CROSS (VERTICAL) SECTION OF CANNEL COAL FROM THE MERCER SHALE (UPPER POTTSVILLE) ON NESHANNOCK CREEK NEAR LEESBURG STATION, PA.

This section shows spore exines, lumps of resin (at left), and a number of yellow bodies, probably colonial algae related by nature and composition to Elaeophyton. The section exhibits the characteristic aspect and constitution of a cannel coal in which spore exines predominate and in which occur also minor amounts of resin lumps, alga colonies, fragments of cuticle, etc. × 200

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ANIAKCHAK CRATER, ALASKA PENINSULA

BY

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ANIAKCHAK CRATER, ALASKA PENINSULA.

By Walter R. Smith.

The discovery of a gigantic crater northwest of Aniakchak Bay (see fig. 11) closes what had been thought to be a wide gap in the extensive series of volcanoes occurring at irregular intervals for nearly 600 miles along the axial line of the Alaska Peninsula and the Aleutian Islands. In this belt there are more active and recently active volcanoes than in all the rest of North America. Exclusive of those on the west side of Cook Inlet, which, however, belong to the same group, this belt contains at least 42 active or well-preserved volcanoes and about half as many mountains suspected or reported to be volcanoes. The locations of some of these mountains and the hot springs on the Alaska Peninsula and the Aleutian Islands are shown on a map prepared by G. A. Waring.[1] Attention has been called to these volcanoes for nearly two centuries, but a record of their activity since the discovery of Alaska is far from being complete, and an adequate description of them as a group has never been written. Owing to their recent activity or unusual scenic beauty, some of the best known of the group are Mounts Katmai, Bogoslof, and Shishaldin, but there are many other beautiful and interesting cones and craters.

Aniakchak Crater (Pls. XLI, XLII) was discovered in August, 1922,[2] by a United States Geological Survey party, in charge of R. H. Sargent, topographic engineer, in the course of a reconnaissance topographic and geologic survey of the country west of the Aleutian Mountains between Wide and Aniakchak bays. The first evidence of an ancient volcanic eruption in the district was observed 30 miles northeast of the crater, in the form of thin deposits of fine ash concentrated in small depressions on the hillsides. As the work progressed southwestward the deposits of volcanic ash became more numerous and the material coarser. Along Ray Creek, 18½ miles from the crater, pieces of scoria and fine ash had consolidated and subsequently been cut by the stream until vertical walls stand 6 to 12 feet high on both banks. (See Pl. XLIII, *A*, *B*.) The floor of the broad valley of Cinder River was found to be entirely covered by volcanic ejecta, but the source of the material was not discovered until the summit of Elephant Mountain was occupied by Mr. Sargent and the writer. Prior to the view of the crater, however, locations on the topographic map of a group of peaks in the distance had assumed the form of a circle, but the reason of the arrangement was not suspected.

Aniakchak Crater is 24 miles northwest of Aniakchak Bay, approximately in the central part of the Alaska Peninsula, on the divide between the Pacific Ocean and Bering Sea. Although there are no trails, the district is easily accessible from either side of the peninsula. Aniakchak River, the largest stream on the peninsula flowing into the Pacific Ocean, rises within the crater and breaks through the east side of the rim in a narrow and picturesquely castled canyon which has been named "The Gates" (Pl. XLIII, *C*), from two long, nearly symmetrical mountain spurs that diverge from the canyon, one on each side of the river, and inclose the upper valley. The crater is nearly circular in outline and has a maximum diameter of 6¾ miles and a minimum diameter of a little over 5¾ miles. The lowest part of the crater floor is 1,100 feet above sea level and contains Surprise Lake, a body of water with an area of 2 square miles. The walls are well preserved and rise almost vertically in places to altitudes of 1,200 to 3,000 feet above the bottom of the crater. A large truncated cinder cone, the summit of which is 2,200 feet above Surprise Lake, occupies the south-central part of the area inclosed within the crater rim.

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[1] Waring, G. A., Mineral springs of Alaska: U. S. Geol. Survey Water-Supply Paper 418, pl. 1, 1917.

[2] It has recently been reported that W. W. French, an engineer, and party visited the crater in July, 1921, but no report of the discovery was made at that time.

The crater was first mentioned without a name by R. F. Griggs[3] in a book that was printed shortly after the return of Mr. Sargent's party. Under the name "Old Crater" its position is indicated on the map of Alaska published by the Survey in 1923. A very brief description of the crater was included in a report[4] on the geology of the district. In a chronologic account of observed volcanic activity in Alaska, Grewingk[5] gives the geographic position of Veniaminof volcano as

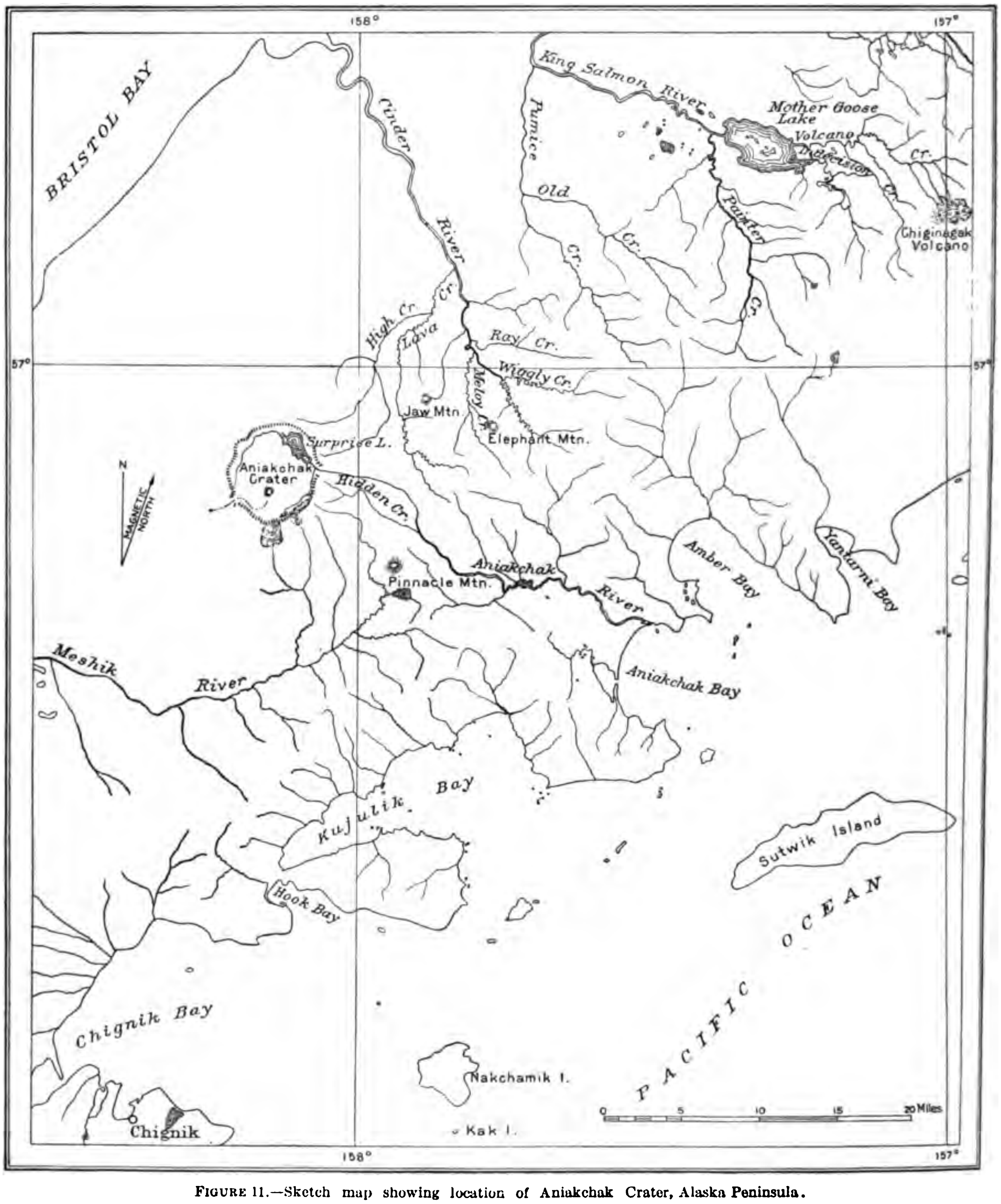

FIGURE 11.—Sketch map showing location of Aniakchak Crater, Alaska Peninsula.

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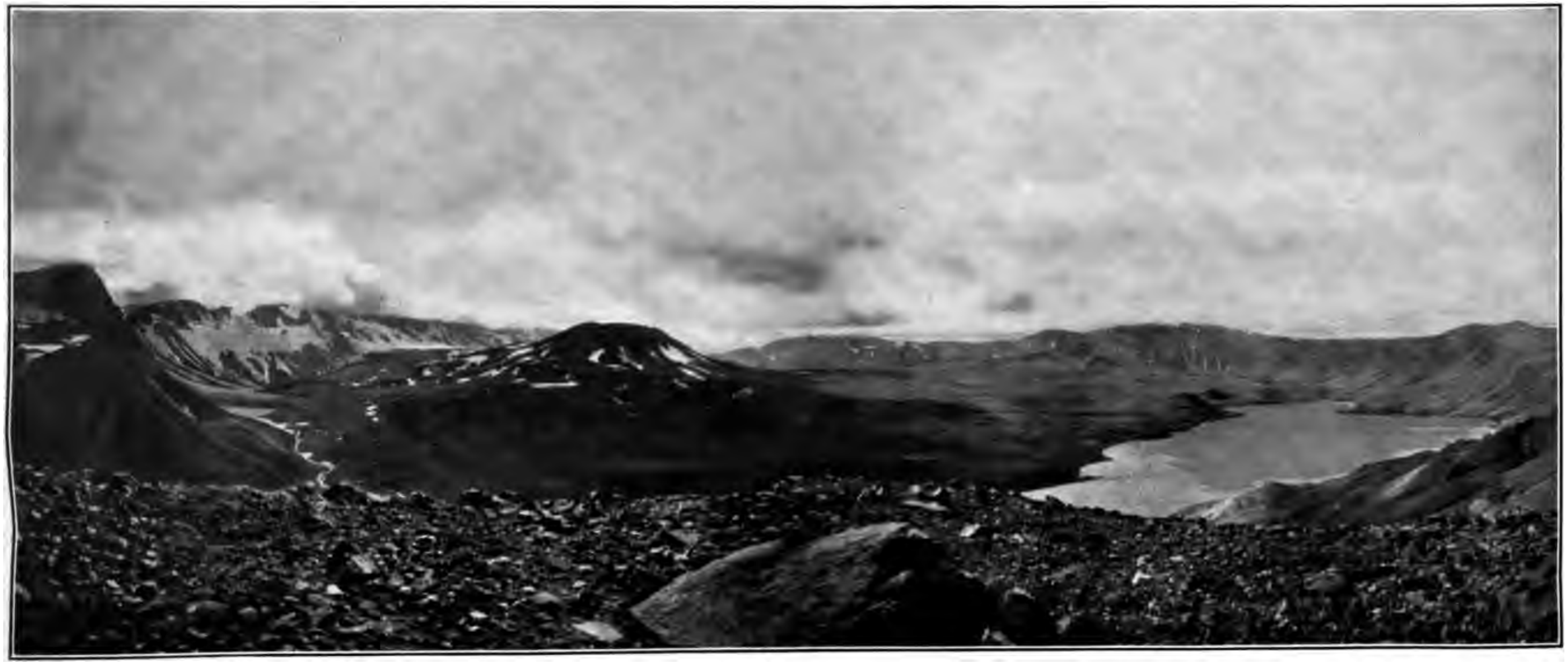
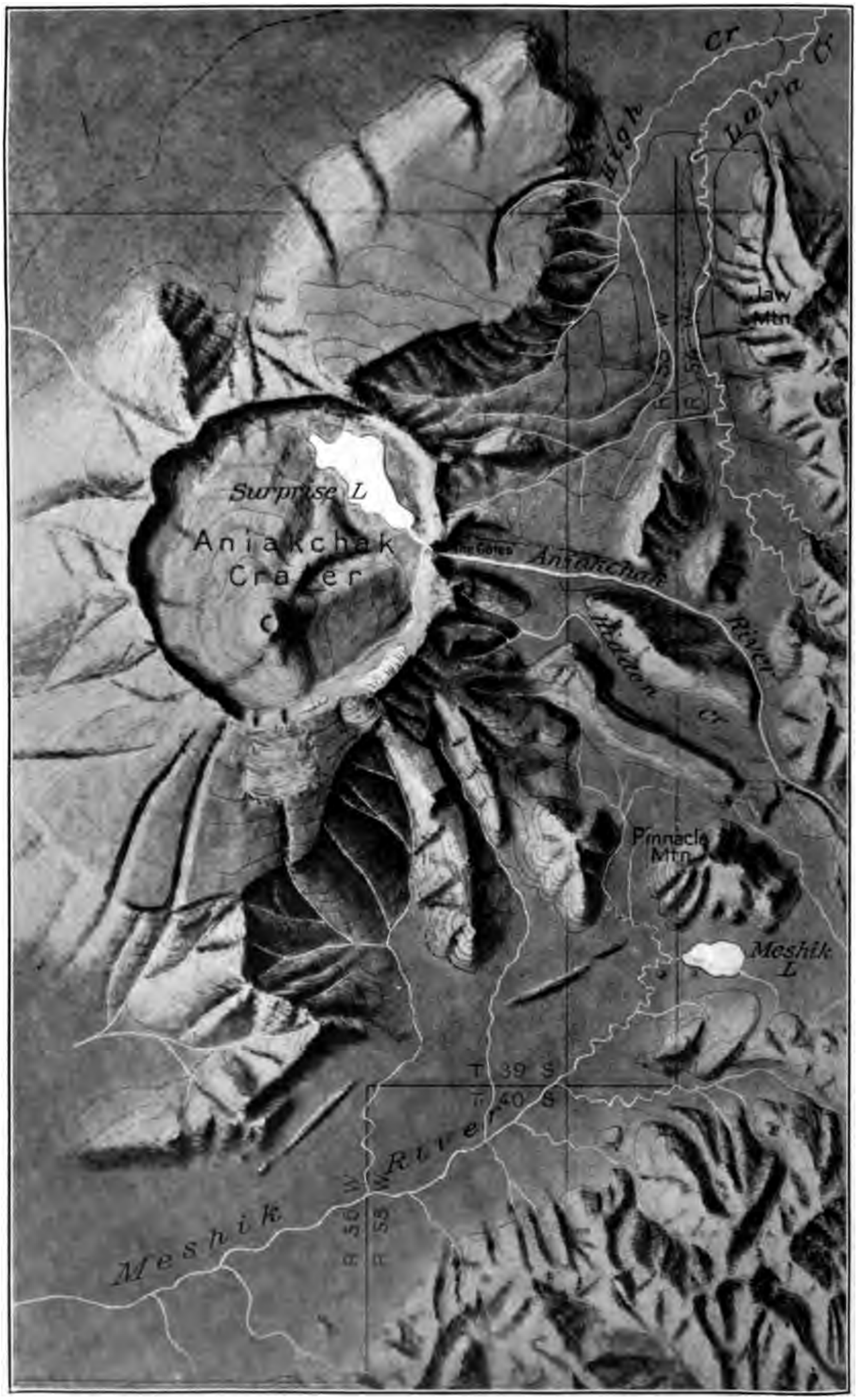
[3] The Valley of Ten Thousand Smokes, p. 65, footnote, 1922.

[4] Smith, W. R., and Baker, A. A., The Cold Bay-Chignik district: U. S. Geol. Survey Bull. 755, p. 157, 1924.

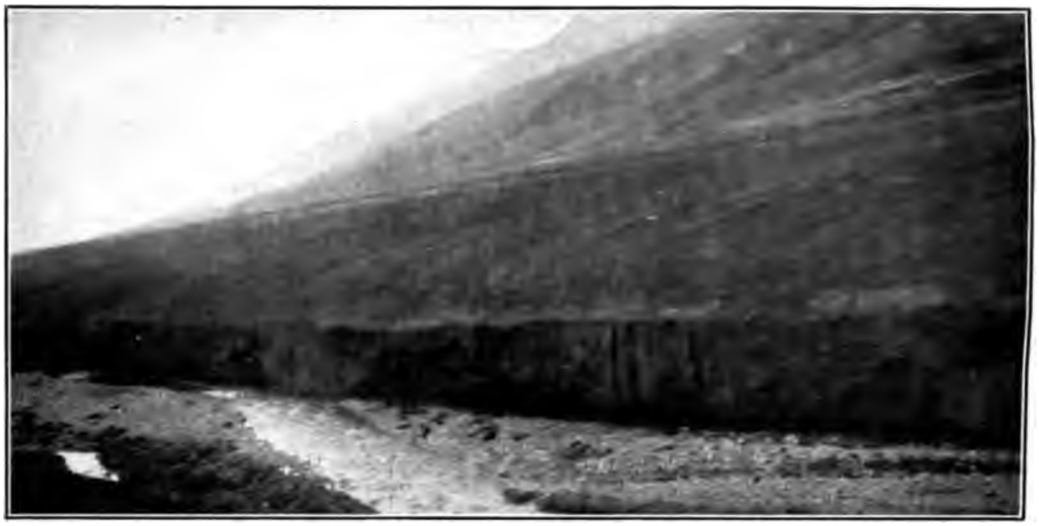
[5] Grewingk, Constantin, Beiträge zur Kentniss der orographischen und geognostischen Beschaffenheit der Nord-west Kuste Amerikas, mit den anliegenden Inseln (with geologic and other maps), St. Petersburg, 1850.



ANIAKCHAK CRATER, ALASKA PENINSULA



RELIEF MAP OF ANIAKCHAK CRATER AND VICINITY, ALASKA PENINSULA



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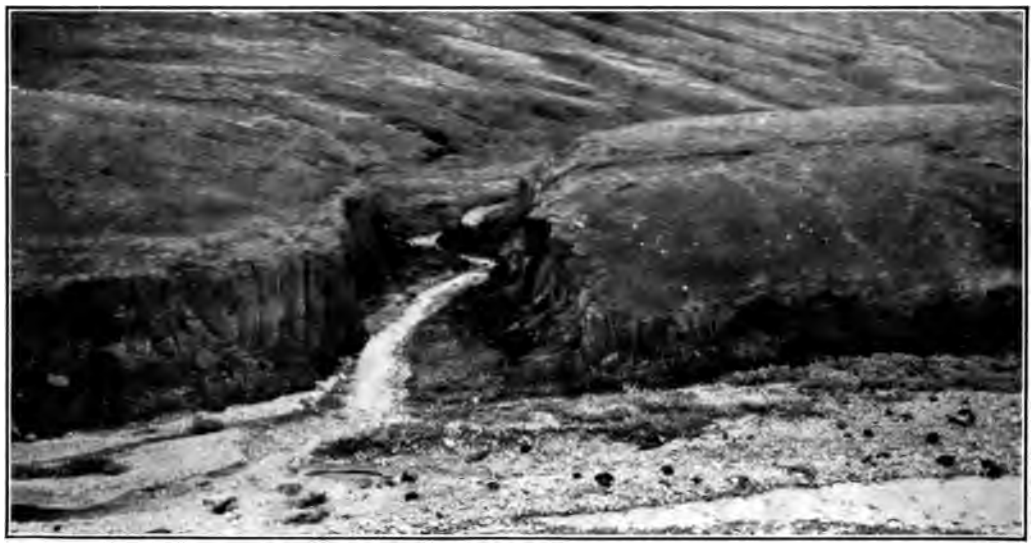
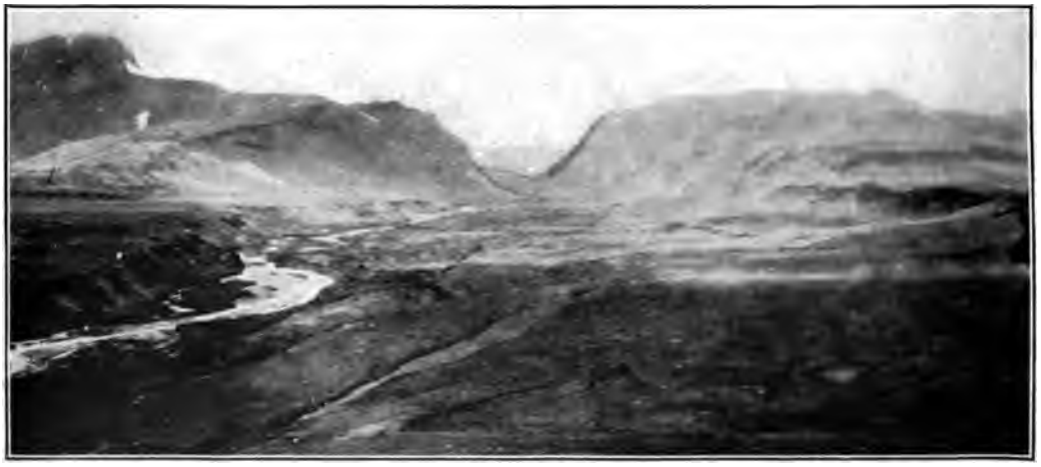
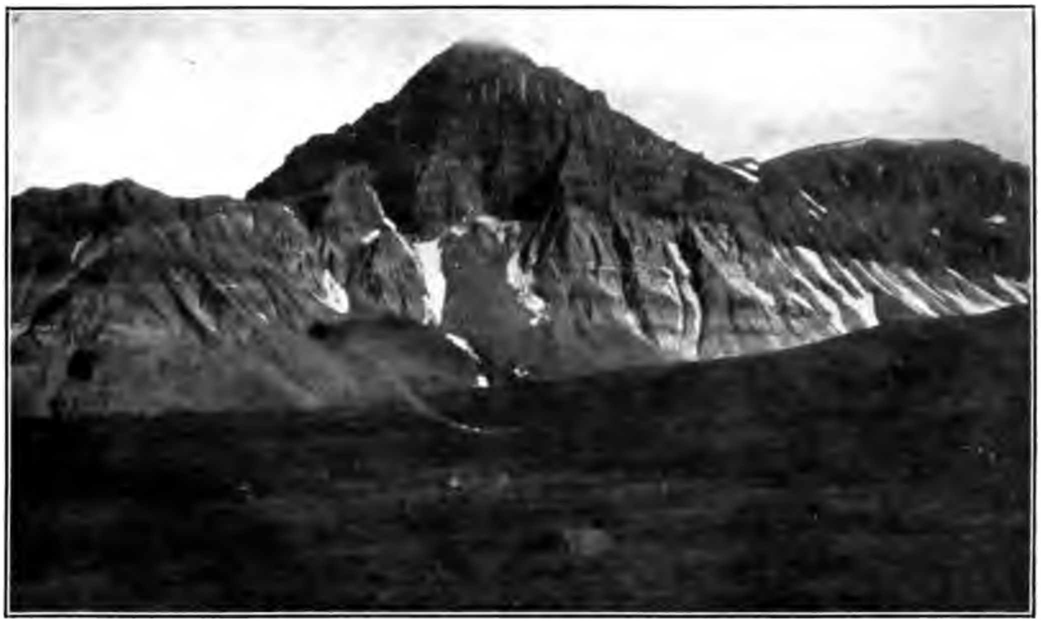


B

A, *B*. EXPOSURES OF VOLCANIC ASH ON RAY CREEK, ALASKA PENINSULA



C. "THE GATES" OF ANIAKCHAK CRATER, ALASKA PENINSULA



A. BLACK NOSE, ALASKA PENINSULA

B. MOUNT CHIGINAGAK, ALASKA PENINSULA

latitude 56° and longitude 158° to 159°. This position is rather close to that of Aniakchak Crater, which is latitude 56° 45′ and longitude 158° 9′, but from the short account given it is quite evident that Grewingk meant the volcano known at present as Veniaminof, latitude 56° 17′ and longitude 159° 15′, and not Aniakchak Crater. Although the Russian scientists and travelers recorded many interesting and valuable observations regarding the volcanoes of Alaska Peninsula, they made no mention, so far as known to the writer, of the immense crater discovered in 1922. It is quite probable that some of the Russian fur hunters, or perhaps a prospector or trapper of more recent days, came across the crater but either failed to recognize it as such or failed to report it. Inquiries were made of the inhabitants of Chignik, the nearest settlement, and of local trappers, all of whom knew nothing about the crater. The present paper is based on observations made by the writer during a few hours. Time was not available to determine the age of the crater or the exact manner in which it was formed.

The observer at a distance would not suspect the existence of a huge crater within the cluster of rather gentle peaks which are separated from the other mountains of the district by broad level areas. The valleys of Meshik and Aniakchak rivers west of the crater are in general less than 200 feet above sea level. The boldest portion of the outer rim of the crater is along the east side of the mountains, where cliffs rise abruptly from the tributary valleys of Aniakchak and Meshik rivers. Over these precipitous cliffs many streams cascade from the glaciers near the summit of the rim. One of these streams has a vertical fall of at least 1,000 feet. The west and north sides of the rim slope more gently away from the crater and are covered to a great depth by ash and cinders. Gullies 30 feet deep on these slopes do not expose the solid rock beneath but show rudely stratified layers of ash and large lava and scoria boulders 4 feet and less in diameter.

The panorama of the crater (Pl. XLI) conveys a rather poor conception of its magnitude, owing to the large size of the area inclosed within the proportionally low rim and to the absence of an object of known dimensions. However, the greatest length of Surprise Lake visible in the photograph is 2½ miles, and the small cones near the upper end of the lake rise about 200 feet above the floor of the crater. The summit of the large cinder cone is 4½ miles from the point at which the picture was taken; the mountains beyond the cone are 6 miles from the observer. The inner wall is abrupt—at places nearly vertical—and so far as known it can not be easily descended except just north of The Gates. A view of Black Nose (Pl. XLIV, *A*), the peak immediately south of The Gates, taken from a cinder ridge within the crater, gives an idea of the steepness of parts of the inner wall. The south side of the crater rim affords a gathering ground for the snow, and here vigorous alpine glaciers have been formed on the steep slopes. Evidence of slumping along the inner wall was not noted except for several talus slopes in the canyon of Aniakchak River and near the base of Black Nose. The circumference of the crater is nearly 19 miles. The rim is broken in two places—the sharp notch through which Aniakchak River flows and a depression on the west side which was not seen in 1922 but has been reported by M. W. Taylor, of Seattle, who visited the crater in 1923. On the south side the highest point on the rim is 4,200 feet above sea level and 3,000 feet above Surprise Lake. This peak and several others close by were obscured by clouds at the time the photograph reproduced in Plate XLIV was taken. The greater part of the crest of the rim is not jagged, although Black Nose and several other sharp peaks rise above the average altitude, which is approximately 3,000 feet.

Along the north and northeast sides the inner wall is partly covered by detritus, but in the few exposures seen the rocks appeared to be layers of pink and black lava, probably obsidian, several hundred feet thick, overlying a light-colored quartz diorite. Most of these exposures are inaccessible and were not closely examined, but a specimen of the quartz diorite was taken on the outer wall northeast of the crater. Exposures in the cliffs along the canyon and near the bottom of Black Nose consist of nearly horizontal sedimentary rocks, chiefly very massive gray sandstone. In the lower 500 feet the rocks exposed in the canyon are abundantly fossiliferous; the greater part of the fossils belong to several species of *Aucella* that are characteristic of the Naknek formation, of Upper Jurassic age. From a distance the summit of Black Nose apparently consists of lava, but the upper portion may be in part sedimentary rock, presumably of Tertiary age. The unconformity and the contrast in lithology between the rocks of the two kinds can be seen in Plate XLIV, *A*. Although the high mountains forming the south side of the rim were not closely examined, they probably consist entirely of sedimentary rocks, the greater part of which are Upper Jurassic. A rugged spur north of the north wing of The Gates is composed of very coarse agglomerate or tuff similar to that overlying large areas in the vicinity of Aniakchak and Kejulik bays. Most of the large and small boulders that make up the agglomerate are angular, but some are rounded. Individual blocks attain 16 feet in diameter and display the darker shades of red, green, and gray. Many of the boulders are black, and all of them show a scoriaceous texture.

The area of the bottom of the crater is approximately 30 square miles. The entire floor is covered to an unknown depth by black and gray scoria ranging in coarseness from very fine material to pieces several feet in diameter. About one-third of the floor is level; around the base of the large cone ridges of cinders, 200 to 800 feet high, radiate toward the crater wall. The formation of the cones and the position of the material within the rim are undoubtedly the results of activity subsequent to the major eruptions that produced the great crater. The later activity probably decreased the original depth of the crater by partly filling it with cinders, The upper 800 feet of the large cone is remarkably circular and well preserved. It is thought to be formed entirely of cinders, as no lava was observed on the ridges around the base. The summit is truncated and may be slightly depressed. An attempt was made to reach the top, but traveling over the loose material is wearisome, and the attempt was given up late in the evening with the realization that a trip of 10 miles to camp was yet to be made. The small cones near the head of the lake were not examined. Toward the west side of the crater, 5 miles from the writer's nearest point of observation, another small cone, which was not caught by the camera, could be seen by aid of a field glass. Near this cone a curious bowl-shaped deposit of white material, probably formed by hot mineral waters, stands out in contrast to the surrounding black scoria, which appeared to be very coarse at that locality. Only a rough estimate of the dimensions of the bowl can be given, but it is at least 200 feet in diameter.

Surprise Lake, in the northeastern part of the crater, is irregular in outline and has a maximum length of 2½ miles and average width of three-fourths of a mile. It covers an area of nearly 2 square miles, but the bluish-green color of the water indicates that the depth is not great. The lake may have formerly covered a much larger area, before the river had deepened its channel through the canyon, but terraces or high-water marks could not be detected on the wall at the few places examined. An ill-defined bench occurs well up on the sides of the cinder cone, however, but the bench is not continuous nor sufficiently well preserved to consider it an ancient lake shore. A small circular lake or pool several hundred feet higher than Surprise Lake is situated at the base of Black Nose. Although a stream of considerable size flows from the lake and unites with Aniakchak River just inside The Gates, the lake has no affluents and must derive its supply of water from the snow fields and glaciers by seepage through the cinders.

The narrow notch in the crater's rim through which Aniakchak River flows has undoubtedly been deepened by the erosive power of the stream, which is very turbulent as it emerges through The Gates. The break in the wall, however, is thought to be caused by a rift, which may extend across the crater and account for the depression on the west side. No evidence of relative vertical displacement of the opposite sides of the canyon was noted. The photograph of The Gates (Pl. XLIII, *C*), taken through the haze from a point 5½ miles down the valley, does not do justice to their profoundly impressive beauty. Several terraces formed by the river in the ash and pumice can be seen in the foreground. The crater can be entered through The Gates without difficulty on the south side of the river. The stream was too swift to be waded within the canyon when it was visited in August, and an attempt to pass through on the north side of the river terminated by climbing a precipitous cliff 1,600 feet high.

Only the east side of the crater was visited, but the country to the north could be seen from Jaw Mountain and the southeast outer wall from Pinnacle Mountain. All the valleys of the surrounding country for many miles are covered by thick deposits of ejecta from the crater. The material consists of fine ash, fragments of black and pink lava, and gray, black, and red pumice. The greatest observed thickness is exposed in the steep banks of Lava Creek. The stream has developed many beautiful terraces and its present bed, west of Jaw Mountain, is cut, perhaps 50 feet, into a deposit of black volcanic glass, as reported by Mr. Sargent. The glass or obsidian is 10 miles from the nearest point on the crater's rim, and whatever its source it was extruded before the great eruptions of the volcano, as it is overlain by at least 150 feet of loose material, the greater part of which is black pumice. This is the only lava seen in place except on the inner wall of the crater, but many fragments of black obsidian, containing a few glassy lath-shaped crystals of feldspar, were found on the mountains many miles from the crater. Indications of extinct fumaroles were sought in the ash-covered area east of the crater, but much of the volcanic material has been worked over by streams, and no evidence of fumarolic activity was found. The upper valley of Meshik River and also the valley of Aniakchak River in the vicinity of Albert Johnson Creek have been filled with volcanic débris to such an extent that the present valley floors are very broad and nearly level. A few low isolated hills near the margins of the level area appear to have been partly buried, with only their summits left exposed, but this is probably an illusion. Several high mountains southeast of the crater are sharp-peaked, especially Pinnacle Mountain, and are composed of hornblende andesite. A stream of considerable size, Hidden Creek, a tributary of Aniakchak River, flows through a subterranean channel beneath the ash and cinders for a distance of 5 or 6 miles and emerges on the west bank of the river. The Aniakchak is about 100 feet wide and 4 feet deep below the North Fork. The current is swift enough to transport small pieces of pumice along the bottom. At 4 miles from its mouth the river has eroded a picturesque gorge through a thick deposit of volcanic agglomerate. The southwest side of the gorge is formed by a rugged spur that projects across the valley from the hills to the southwest and is locally known as Cape Horn. (See fig. 11.) The river is navigable by small boats as far as the meanders below the mouth of Mystery Creek.

A broad marshy lowland lies between the shore line of Aniakchak Bay and the hills toward the northwest. In this area a remarkable series of nine crescent-shaped ancient beaches can be seen from the mountains north of the river in the form of low ridges conforming in direction to the present shore line. A large part of the material in these ridges consists of volcanic ash and pumice washed ashore by the waves after having been trsnsported into the bay by the river. The bay is uncharted and is not a protected harbor, although deep water is reported by masters of fishing schooners who have entered the bay. Hook Bay, 25 miles directly south of the crater, affords an excellent harbor for boats of moderate size. An old trail leads from this bay over the mountains toward Meshik River valley and is probably the best route from the Pacific coast to the crater, although in fair weather a landing can be made at the mouth of the river at Aniachak Bay. From this point the distance to the crater is not so great as from Hook Bay, and the route is over level country. Chignik is the nearest settlement and is 40 miles southwest in a direct line from the crater but at least 60 miles by trail. A trapper's cabin has been built near the lagoon at Aniakchak Bay and one on the south side of the valley below Albert Johnson Creek. The trappers occupying the cabins during the winter had traveled over the cinders as far west as Meshik Lake for many years, but they did not know of the existence of Aniakchak Crater.

Vegetation has gained a footing in places throughout the area covered by ash, and even within the crater several tufts of grass and low flowering plants were seen. Large areas, however, within a radius of 20 miles of the crater, are entirely barren of plant life and have the appearance of arid plains. Alder bushes have grown to a height of 6 feet in the valleys of High and Lava creeks and furnish sufficient fuel for camp purposes, but they are not straight enough to be used for tent poles. Foxes and Kodiak bears inhabit the region, Small herds of caribou were seen near the valley of Pumice Creek.

The wide general use of the term "crater" includes several varieties or types, which have been differentiated as impact craters, subsidence craters, upbuilt craters, and explosion craters. An impact crater may be formed by the fall of a body, such as a large meteorite or a projectile from a cannon. Such a bowl-shaped hollow or pit may have nothing in common with volcanic activity. A subsidence crater is a depression below the general level of the country or a concave area on a mountain, made by the collapse of the roof of a cavity. In limestone countries such depressions are common, but the use of the term is restricted by many geographers to pits occurring in volcanic regions. These pits are usually caused by the collapse of cavities formed in volcanoes by the eruption of lava and other material. Craters formed in this manner are also known as caldrons. The largest and some of the best-known craters on the earth are of this variety, to which belong Kilauea, in the Hawaiian Islands (2.93 miles in diameter); the pit of Crater Lake, Oregon (5½ miles in diameter): Ngorongoro, East Africa (12 miles in diameter); and Aso-san, in Japan (dimensions, 9 by 14 miles). An upbuilt crater has the form of a more or less circular mound surrounding an aperture, relatively small in diameter but usually deep, which serves as a vent for the lava, ash, and fumes thrown out by a volcano. This is the normal and most common type of craters and occurs on the summits of Lassen, Etna, Cotopaxi, Fuji, and scores of other volcanoes. Stromboli, in the Mediterranean Sea, is taken as the type of the explosion craters. Better examples, however, are known, such as the crater formed by the ancient explosion of Vesuvius, A. D. 79, of which Mount Somma is a remnant, and the ruins of Krakatoa in 1883 and of Katmai in 1912. Excavations made by erosive agents have been referred to and classified as craters, but they have nothing to do with volcanic action.

All the evidence now available points to the origin of Aniakchak Crater by explosive activity and not by subsidence. Besides the vast quantities of rather fine material thrown from the crater and concentrated in the valleys of the surrounding country, huge projectiles were hurled many miles. On the north slope of Elephant Mountain, 1,000 feet above the valley of Meloy Creek and 23½ miles from the center of the crater, a block of black obsidian was found which measured at least 2 cubic feet in volume. About 14 miles southeast of the crater an angular mass of sandstone, 5 feet in diameter and containing fossils similar to those found near Black Nose, occurs near the summit of a small hill composed of agglomerate. The large boulder is not waterworn, and there is slight probability that it was carried to its present position by a glacier. The ash contains smaller fragments of sandstone that have the same lithologic character as that exposed in the southeast wall of the crater and were not derived from rock in the immediate vicinity in which they were found. That tremendous explosive forces were active at the time the present crater was formed is quite evident. All the known craters of the world as large as Aniakchak Crater or larger are thought to have been formed by subsidence. Katmai Crater, 3 miles in diameter, 151 miles to the northeast, was formerly considered the largest crater of the explosive type known, but it is greatly surpassed by Aniakchak Crater, 6¾ miles in diameter. In diameter and general outline the caldron of Crater Lake, Oreg., and Aniakchak Crater are remarkably similar, although the two are of entirely different types.

The form of the mountain mass that occupied the present site of the crater prior to the eruptions that resulted in the formation of the depression can of course only be conjectured. Before the existence of the volcano the area now within the crater was probably occupied by one or more mountains of moderate altitude—that is, by analogy with other mountains in the district, between 3,000 and 4,000 feet—which were composed of very slightly folded sedimentary rocks, intruded on the north by a large mass of quartz diorite. Why volcanic vents should be formed near the summits of high mountains composed of nearly horizontal strata is difficult to explain, but on the Alaska Peninsula many of the active and extinct volcanoes originated in mountains of this type. This is especially true of the volcanoes toward the northwest, of which Mounts Katmai, Magiek, Peulik, and Chiginagak are examples. These volcanoes and many others on the Alaska Peninsula have formed cones and increased their altitudes to heights ranging from 5,000 to nearly 10,000 feet by successive lava flows over the sedimentary rocks. Mount Chiginagak (Pl. XLIV, *B*), an active volcano 43 miles northwest of Aniakchak Crater, is an impressive and typical example of an upbuilt cone. That a similar cone once towered above the site of Aniakchak Crater is suggested by beheaded lava flows, remnants of which are exposed on the east wall of the crater, on the summit of Black Nose, and possibly in the bed of Lava Creek. An imaginary cone reconstructed a mile in height above the present floor of the crater would be slightly over 6,000 feet above sea level, an altitude which is very low in proportion to the diameter of the base and also relatively low if compared with the altitude of other volcanic cones. But even if a low cone is postulated the amount of material to be accounted for is enormous and the force necessary to remove it in one or several explosions is beyond imagination. The capacity of the crater alone, if 1,600 feet is taken as the average height of the rim, is about 9 cubic miles. Subtracting 1 cubic mile for the large cinder cone still leaves space for 8 cubic miles within the crater. To this must be added at least 7 cubic miles if the low cone, suggested above, ever existed. Between 300 and 400 square miles of adjacent country on the east and south is known to be covered to various depths by volcanic ash and cinders, and if an equally large area north and west of the crater is also overlain by ejecta, certainly an appreciable part of the supposed total of 15 cubic miles is still to be seen.

Ordinarily the Bering Sea coastal plain on the northwest side of the peninsula is dotted with thousands of small lakes, but in the area north of the crater no lakes could be seen from Jaw Mountain. That all depressions in this part of the plain were filled by material from the crater is a fair deduction. The volume of material ejected from Katmai is estimated at 4.75 cubic miles, but Katmai Crater has a capacity of only 2 cubic miles. The ejection of vast quantities of material from a single source and perhaps during a single period of eruption is not unheard of in volcanism. Capps[6] has estimated a volume of 10 cubic miles of volcanic ash thrown from a vent in the upper White River basin, and other large estimates have been made. Most of these computations, however, were made from measurements of the material ejected and not from the capacity of the crater.

Few data are now available for estimating the age of Aniakchak Crater. However, it is believed to be one of the oldest of the series of volcanoes along the Aleutian Range. That the eruption antedates historic record is suggested by the amount of stream erosion, especially in Lava Creek, and the vegetation of the area, including alders. If the absence of evidence of glaciation since the eruption is taken as a criterion it would appear that the eruption is of post-Pleistocene age. Although the ash is more or less concentrated in the valleys it is not in the form of glacial moraines, and unless an ice sheet in which there was little or no movement covered the entire area, moraines of the loose pyroclastic material would be expected had this material been deposited before glaciation. A few of the valleys, such as that of Ray Creek, in which thick deposits of ash occur, are rather narrow and probably have been formed almost entirely by stream erosion. Most of the valleys are broad and suggest extensive glaciation before they were partly filled by ash. A detailed study is necessary for a more definite age determination.

An examination of the relief map (Pl. XLII) will perhaps convey a better idea of the giant crater than a description. Nearly all distances were scaled from Mr. Sargent's skillfully drawn topographic map, on which the relief map by Mr. Renshawe is based. The topographic map is published separately as the Cold Bay-Chignik map.

The writer wishes to acknowledge his indebtedness to Mr. Sargent for cooperation during the field work and for valuable assistance and criticism in the preparation of this paper. Thanks are also expressed to Mr. Sidney Old, who accompanied the writer into the crater and led the way across Aniakchak River.

The scenery of the Aniakchak district, with its broad prairie-like valleys, margined by majestic, sharp-peaked mountains, is impressive and in many respects unique. The once active scene of terrific earth convulsions is now almost oppressively silent. The coloration of the country is somber and together with the fretfully driven clouds tends to create a rather pleasing weirdness. Aniakchak Crater is one of the great natural curiosities of North America and is certainly worthy of further investigation. Although small in comparison, it is probably the nearest counterpart on earth to the craters of the moon in regard to the manner of its formation. Were it not so remote from the usual paths of travel the setting apart of this crater as a national monument would be justified.

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[6] Capps, S. R., An ancient volcanic eruption in the upper Yukon basin: U. S. Geol. Survey Prof. Paper 95, p. 62, 1915.

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